Stream Temperatures and Steelhead Habitat Suitability in the Guadalupe Watershed during an Experimental Streamflow Study in August 1998

Prepared
by

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ABSTRACT

A study was performed to analyze stream temperature conditions in relation to tolerance limits for steelhead trout *(Oncorhynchus mykiss)* within the Guadalupe Watershed. The effect of reservoirs on stream temperatures was also analyzed. At several locations within the watershed, stream temperatures were compared under two experimental flow regimes. Results show that above the reservoirs, temperatures were suitable for rearing steelhead and did not change substantially with distance upstream. Shallow reservoirs had a warming effect on stream temperature while deep reservoirs had a cooling effect. With a few exceptions, water temperatures increased with distance downstream of the reservoirs. At several locations water temperatures were significantly higher during the high-flow period ($p<0.05$). The distribution of stream temperatures suitable for rearing steelhead did not differ between the two flow regimes. An exception was observed at one location. Under both experimental flow regimes, air temperature was significantly more influential on stream temperature than flow ($p<0.05$). These results provide preliminary insight to the temperature effects of two different flow regimes. Before sound management decisions can be made, further analyses of reservoir and habitat data are needed. Final results should provide a technical basis to help guide decisions regarding water management as well as the development of future studies.

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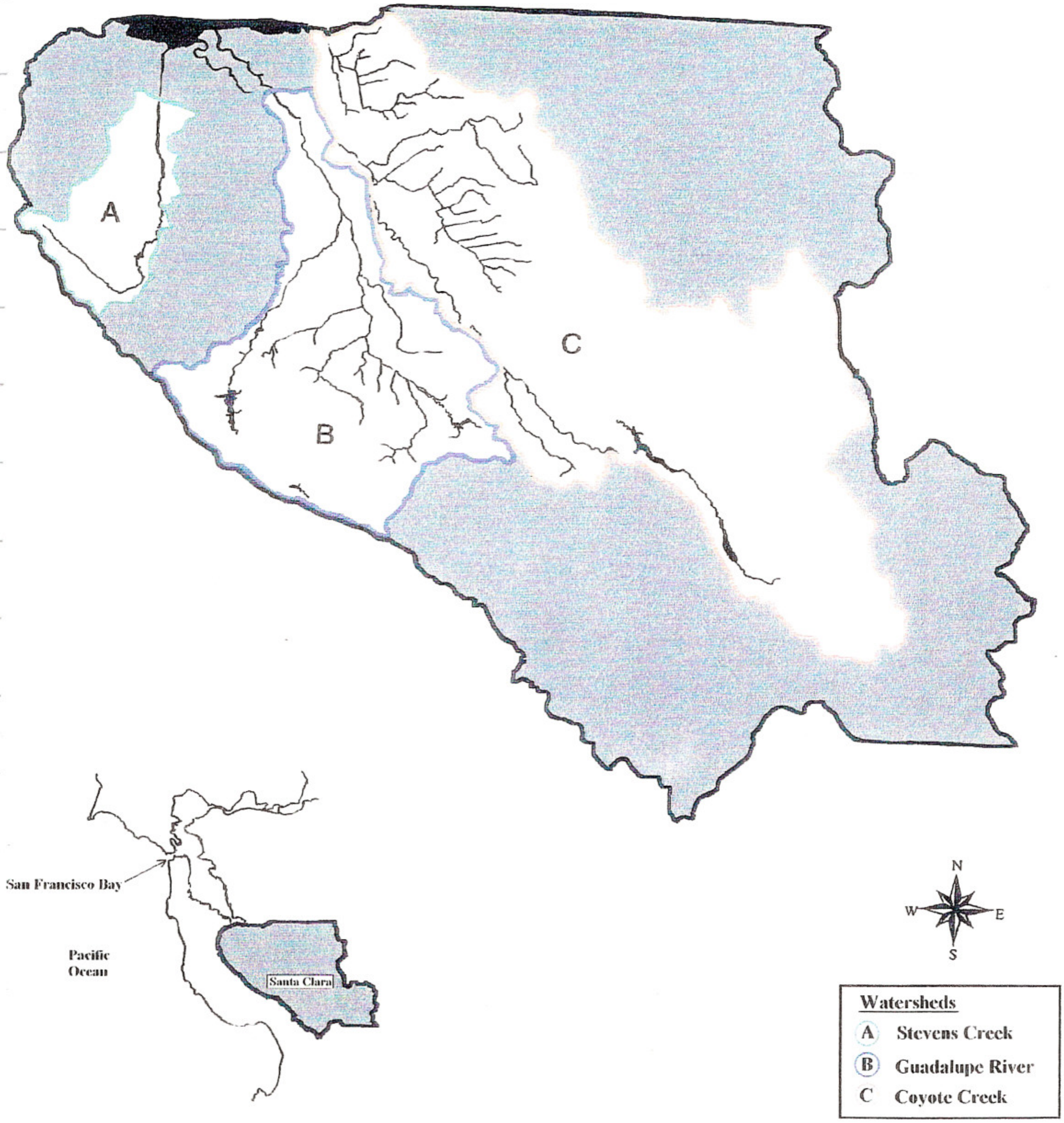
INTRODUCTION

The Santa Clara Valley Water District (SCVWD) provides wholesale water and flood protection to 1.6 million residents as well as municipal and industrial sectors in Santa Clara County, California. Within the county's 3,400 km^2 (1,300 mi^2), the SCVWD manages 11 reservoirs and maintains 1,018 km (700 mi) of creeks and rivers. Major watersheds within the county provide habitat to a variety of fishes, including steelhead trout *(Oncorhynchus mykiss)* and chinook salmon *(O. tshawytscha)*. Along with rising demands for water supply and flood protection, public concern has focused on fisheries and aquatic resources potentially impacted by SCVWD facilities and operations.

These concerns resulted in a water rights complaint (363:MAM:262.0[43-1-01]) filed with the State Water Resources Control Board (SWRCB) by the Natural Heritage Institute (NHI). In the complaint the SCVWD was named for alleged violations of the Fish and Game Code, Water Code, Common Law Public Trust Doctrine, and Porter-Cologne Water Quality Control Act. The complaint alleges harm to fisheries and wildlife resources as a result of water appropriations from the Guadalupe River, Coyote Creek, and Stevens Creek, all of which are tributaries to South San Francisco Bay. In addition the National Marine Fisheries Service (NMFS) has recently listed steelhead trout inhabiting the Central California Coast Evolutionary Significant Unit (ESU), which includes Santa Clara County, as a threatened species under the federal Endangered Species Act (ESA)(62 FR 159; August 18, 1997). NMFS is also evaluating the status of fall-run chinook salmon stocks for potential listing under the ESA (63 FR 11481; March 9, 1998).

In an effort to resolve the complaint, and to address endangered species issues, the SCVWD and the California Department of Fish and Game (CDFG) jointly initiated a cooperative process referred to as the Fisheries and Aquatic Habitat Collaborative Effort (FAHCE). Participants include the SCVWD, CDFG, NHI, NMFS, United States Fish and Wildlife Service, and the City of San Jose. A framework for the scientific investigations was developed through this multi-agency process (FAHCE 1998). The primary focus is to identify and examine limiting factors impacting steelhead and chinook salmon populations in the Guadalupe River, Stevens Creek, and Coyote Creek watersheds (Figure 1). Particular attention is given to those factors affected by SCVWD facilities and operations. These investigations will also provide useful data for the



'igure 1. Stevens, Coyote, and Guadalupe Watersheds; Santa Clara County, California.

development of adaptive management programs to meet water demands for human use while balancing aquatic resource needs.

Steelhead, identified as the primary target species for these studies, inhabit Santa Clara County streams (SCVWD 1995-1998). During the winter and early spring, adults may migrate from the Pacific Ocean through the San Francisco Bay and into freshwater tributaries for spawning. Spawning occurs in areas with suitable gravel, streamflow, dissolved oxygen, depth, and water temperature (Barnhart 1986; McEwan and Jackson 1996; Reiser and Bjornn 1979). After emerging from the gravels during the spring and early summer, juvenile steelhead may rear in suitable fresh water habitats for up to three years before migrating to the marine environment (Moyle 1976; Withler 1966). This life history pattern may subject them to critically high temperatures especially during summer months. Elevated temperatures can lead to increased mortality by influencing fish growth rates, physiological functions, swimming ability, and resistance to disease (Hokanson *et al* 1977; Marine and Cech 1998). Steelhead temperature tolerances vary depending on several factors including life stage, genetic adaptation, dissolved oxygen, and acclimation time (Bell 1986; Bovee 1978; Hanson 1991; Hokanson *et al* 1977; Hooper 1973; Moyle 1976; Raleigh *et al* 1984; Wagner 1974). Water temperatures are influenced by several factors including water-year, reservoir release temperature, streamflow, effluent seepage, ambient air temperature, wind speed, riparian vegetation, channel geomorphology, and local topography.

One element of the FAHCE plan is to examine alternative flow regimes which may change conditions currently limiting fisheries habitat (FAHCE 1998). In cooperation with SCVWD hydrologists and facility operators, the FAHCE Technical Advisory Committee developed a plan to evaluate streamflow-temperature relationships regarding steelhead habitat within the Guadalupe watershed during the summer of 1998. Specific objectives were as follows:

- Monitor summer water temperatures along the longitudinal gradients upstream of Lexington, Guadalupe, and Almaden reservoirs

- Examine the effect of reservoir impoundments on outflow temperatures from Lexington, Vasona, Guadalupe, and Almaden reservoirs

- Examine the temperature effects of two experimental streamflows, as well as other factors such as air temperature, along the longitudinal gradients of Guadalupe, Alamitos, and Calero creeks, and the Guadalupe River

- Evaluate the potential effects of measured water temperatures on the geographic distribution, availability, and quality of juvenile steelhead rearing habitat

This report documents methods and results of the temperature components of this study. A companion technical report is being prepared to document the streamflow effect on physical components regarding steelhead habitat.

STUDY SITE

The Guadalupe River watershed encompasses approximately 441 km^2 (170 mi^2) of land, ranging in use from dense forest and rural development in the upper reaches to annual grassland and heavily urbanized areas along the lower tributaries and mainstem of the Guadalupe River. The streamflow-temperature study primarily encompassed reaches downstream of the reservoirs in Guadalupe, Alamitos, and Calero creeks, and the Guadalupe River downstream to Montague Expressway (Figure 2). The study site also included locations upstream and immediately downstream of Lexington, Vasona, Guadalupe, and Almaden reservoirs (Figure 2).

A continuous canopy cover exists primarily in the upper tributaries and in some sections of the Guadalupe River. In other reaches of the Guadalupe River, and lower sections of its tributaries, riparian vegetation is sparse and discontinuous. Dominant overstory vegetation includes species such as western sycamore *(Platanus racemosa)*, Fremont cottonwood *(Populus fremontii)*, arroyo willow *(Salix lasiolepis)*, and valley oak *(Quercus lobata)*.

Anadromous fish species presently known to occur in the watershed are steelhead trout, chinook salmon, and Pacific lamprey *(Lampetra tridentata)*. Native resident species include rainbow trout *(O. mykiss)*, Sacramento sucker *(Catostomus occidentalis),* prickly sculpin *(Cottus*

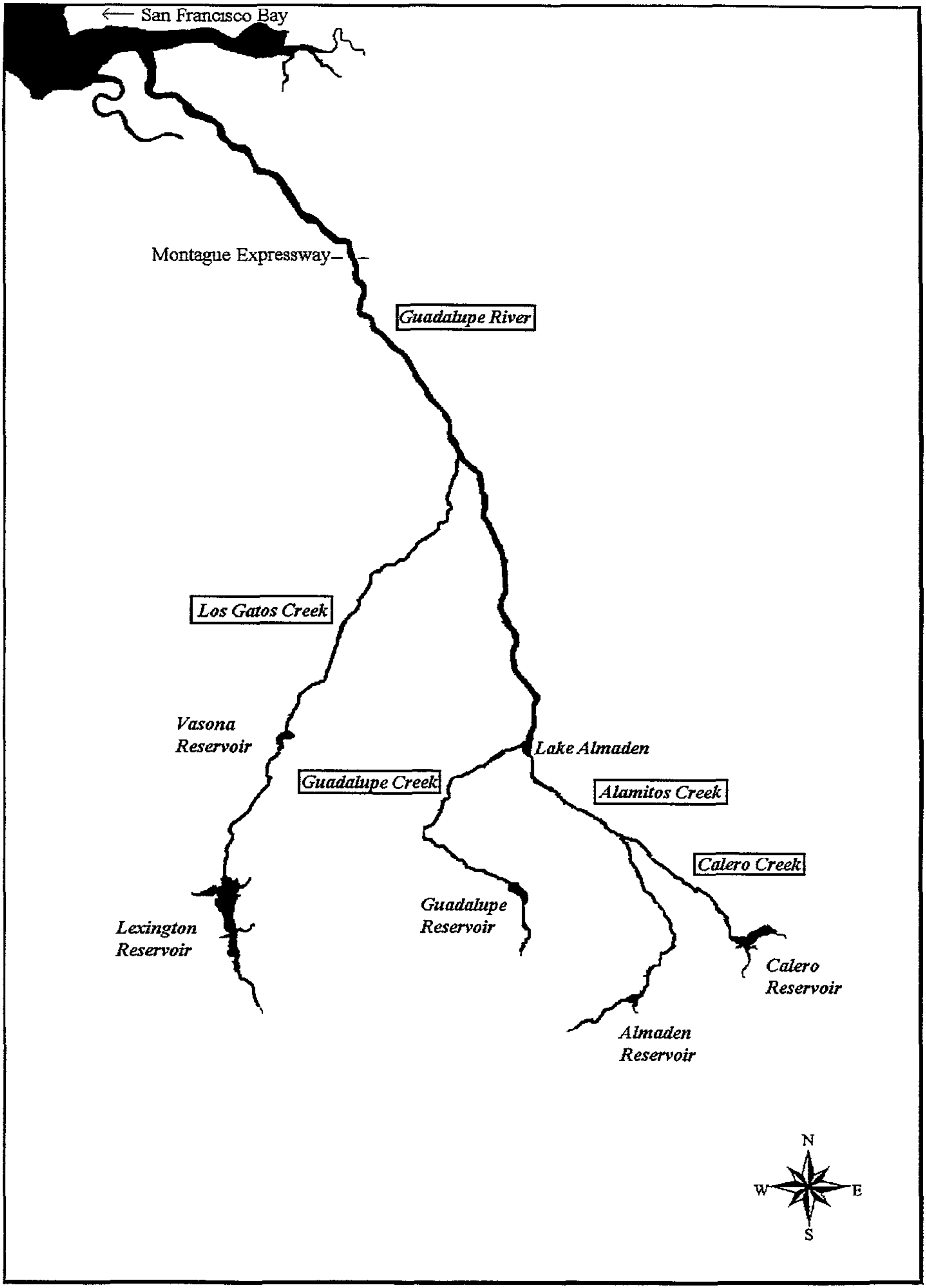


Figure 2. Study site within the Guadalupe Watershed.

asper), riffle sculpin *(C. gulosus)*, hitch *(Lavinia exilicauda)*, California roach *(Hesperoleucus symmetricus)*, and threespine stickleback *(Gasterosteus aculeatus)*. Common introduced resident fish are largemouth bass *(Micropterus salmoides)*, sunfish *(Lepomis sp.)*, brown bullhead *(Ameiurus nebulosus)*, carp *(Cyprinus carpio)*, and goldfish *(Carrassius auratus)*.

Lexington, Vasona, Guadalupe, and Almaden Reservoirs

Lexington, the largest reservoir in the watershed, feeds Los Gatos Creek, including Vasona Reservoir downstream (Figure 2). Vasona Reservoir is relatively small and shallow. Guadalupe, the second largest reservoir included in the study, releases flows to Guadalupe Creek. Almaden Reservoir releases flows into Alamitos Creek. Like Vasona, Almaden Reservoir has a relatively small storage capacity (Table 1).

Table 1. Reservoir depths and storage capacities.

Reservoir	**Maximum Storage (m$_3$ x 10$_7$)**	**Maximum Depth (m)**	**02-Aug Storage (m$_3$ x 10$_7$)**	**02-Aug Maximum Depth (m)**	**30-Aug Storage (m$_3$ x 10$_7$)**	**30-Aug Maximum Depth (m)**
Lexington	2.390	54	2.275	53	2.160	53
Vasona	0.049	6	0.002	4	0.048	5
Guadalupe	0.398	36	0.322	28	0.285	27
Almaden	0.192	30	0.160	27	0.127	25

Guadalupe, Alamitos, and Calero Creeks

Guadalupe and Alamitos Creeks flow from relatively steep, incised canyons, widening to slower and lower-gradient areas downstream. Guadalupe Creek is well-shaded with riparian vegetation in the upper reaches. The lower third of Guadalupe Creek is a relatively low-gradient segment with greatly reduced riparian vegetation. Off-channel percolation ponds are located beside the northwest bank along this reach. Riparian shading is also greatly reduced in the lower gradient reaches in Alamitos Creek. Calero Creek has moderate to dense riparian vegetation along both banks. (Figure 2)

A 3.7-m (12-ft) concrete drop structure (Alamitos Drop Structure) separates these tributaries from the Guadalupe River. At the top of the structure, a wooden flashboard dam is installed during summer months. While maintaining minimum flows downstream, the impounded water provides groundwater recharge and creates an instream recreational lake (Lake Almaden) at the confluence of Guadalupe and Alamitos creeks.

Guadalupe River

The Guadalupe River begins at the drop structure below Lake Almaden and extends for 25.7 km (16 mi) before reaching a tidal influence below Montague Expressway. During the study period, the wetted channel varied in width from approximately 3 to 12.2 m (10 to 40 ft) during the summer.

The river's upper third section, above the confluence of Canoas Creek, is relatively barren with off-channel percolation ponds alternating along both sides of the river. Downstream to the confluence of Los Gatos Creek, the river has a nearly continuous canopy along both banks. Sparse riparian vegetation occurs along the lower segment, downstream of the Los Gatos Creek confluence. (Figure 2)

METHODS

The streamflow-temperature study was performed during August 1998. Water temperature, air temperature, and hydrologic data were monitored at various locations throughout the Guadalupe River watershed. During this period experimental flows were released from three reservoirs. Information regarding general habitat conditions within various stream segments, potential reservoir release strategies were all considered in the experimental design process.

Temperatures were recorded hourly using Optic StowAway temperature monitoring devices (Onset Computer Corporation, Model WTA08 -39 to +75°C). Stream temperature recorders were encased in perforated, steel pipe housings (Figure 3) and attached by cable to well-concealed streamside vegetation or other structures. To prevent damage within the housings, rubber washers were placed around the ends of each unit. Air temperature recorders were attached to dense vegetation along the banks near corresponding stream temperature monitoring stations. Hourly

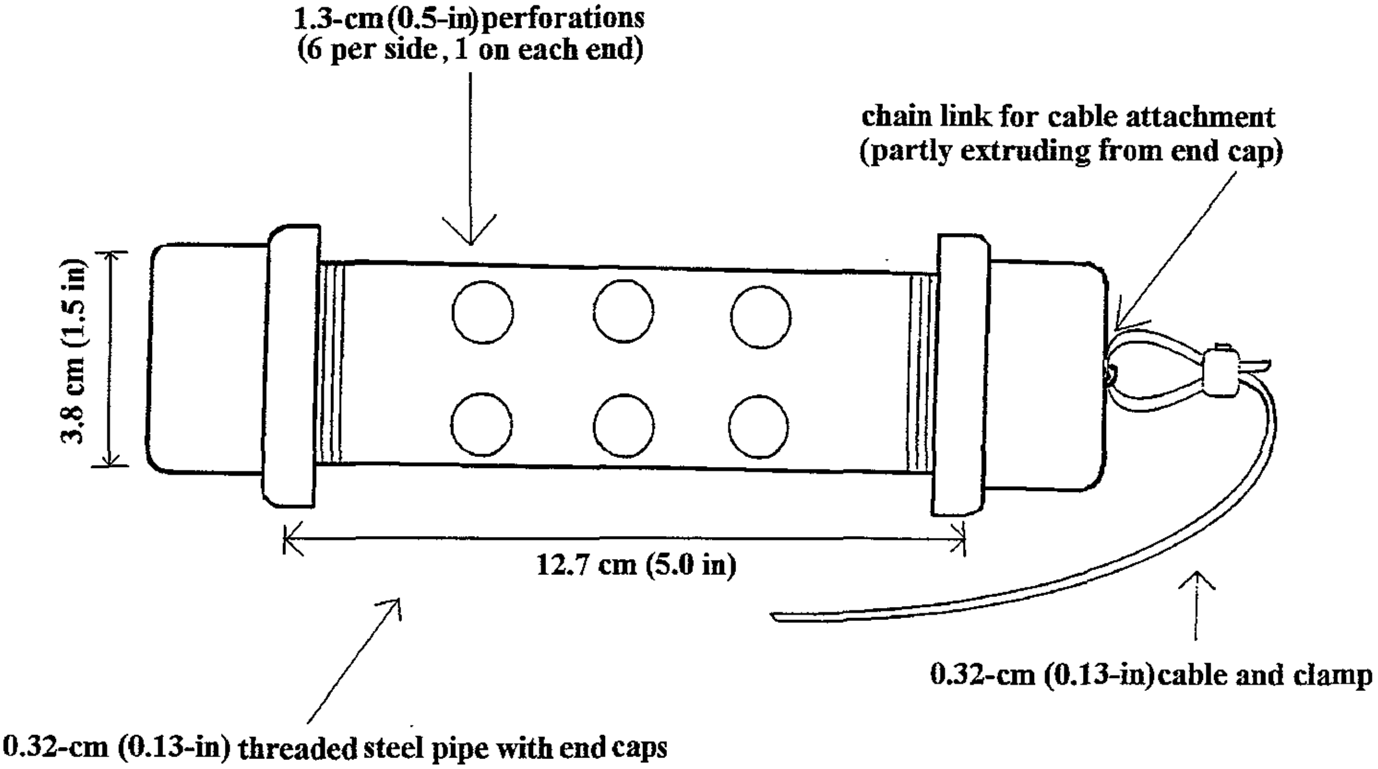

1.3-cm (0.5-in) perforations
(6 per side, 1 on each end)
chain link for cable attachment
(partly extruding from end cap)
3.8 cm (1.5 in)
12.7 cm (5.0 in)
0.32-cm (0.13-in) cable and clamp
0.32-cm (0.13-in) threaded steel pipe with end caps

Figure 3. Metal housing for water temperature monitoring devices.

discharge rates were monitored at permanent stream gauging stations. Additional streamflow measurements were recorded with a current velocity meter (Swoffer, Model 2100).

Water Temperatures above Reservoirs and Reservoir Effects on Water Temperature

Temperature recorders were installed upstream of Lexington, Guadalupe, and Almaden reservoirs. Recorders were placed at the inflows of these three reservoirs. Additional recorders were installed approximately 500 m (1640 ft) upstream of the inflow stations to document longitudinal changes in temperature (Figure 4). Reservoir inflow and outflow temperatures were compared at Lexington, Vasona, Guadalupe, and Almaden reservoirs. Water temperatures were monitored at these locations (Figure 4).

Effects of Streamflow and Air Temperature on Water Temperature

Temperature recorders were installed at fifteen locations downstream of the reservoir outflow stations (Figure 4). Three stations were monitored in Guadalupe Creek, three in Alamitos Creek, two in Calero Creek, and seven in the Guadalupe River. Air temperatures were monitored at seven of these stations (Figure 4). Data were retrieved at the end of each experimental flow period. Time of day was also factored into the analysis of effects on stream temperature.

Experimental flows were released from Guadalupe, Almaden, and Calero reservoirs. Releases were adjusted to reflect both summer flows that would occur naturally, in the absence of reservoirs, and flows augmented by additional reservoir releases. Identification of the experimental flows was based partly on recent seasonal streamflow patterns (1973-1996), as well as late spring and summer flows during years prior to construction of major water storage facilities (1930-1935).

Flow regimes were established in cooperation with SCVWD facility operators and hydrologists. Low-flow conditions were established by setting reservoir release rates equal to reservoir inflow rates. Streamflows were measured above the reservoirs and monitored at permanent gauging stations downstream (Figure 4). Streamflows were also measured bi-weekly to calibrate flow readings at the permanent stream gauging stations. Outflows rates were maintained slightly higher than inflow rates in cases where low flows may have caused critical

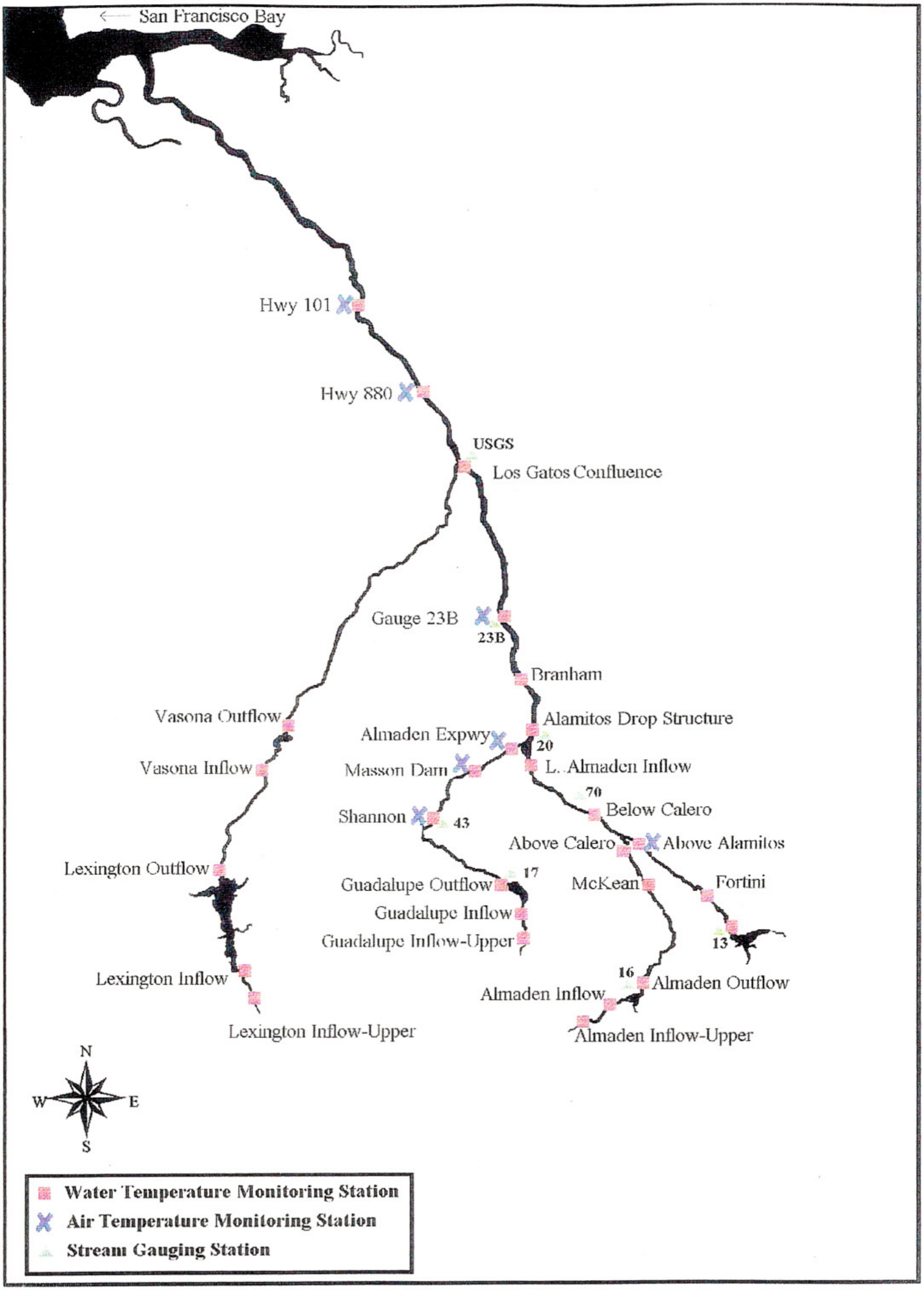


Figure 4. Temperature monitoring and stream gauging stations.

dry-back conditions downstream. The high-flow regime was based partly on the availability of stored water and the feasibility of continuing flows through the summer. Experimental flows were released simultaneously from all three reservoirs (Table 2), thereby allowing evaluation of environmental conditions within the respective tributary and cumulative effects in the Guadalupe River.

Table 2. Mean daily flows during the high- and low-flow test periods.

	Mean Daily Flows (m3/s)			
Station #	**High-Flow Period**	**Low-Flow Period**	**(p)**	**Low-Flow Water Flows Higher or Lower**
Guadalupe Creek				
17	0.3	0.1	0.0001	Lower
43	0.3	0.1	0.0001	Lower
Alamitos Creek				
16	0.3	0.2	0.0001	Lower
70	0.4	0.3	0.0001	Lower
Calero Creek				
13	0.2	0.1	0.0001	Lower
Guadalupe River				
20	0.4	0.2	0.0001	Lower
23B	0.4	0.1	0.0001	Lower
USGS	0.8	0.6	0.0004	Lower

Following initial calibration adjustments, the high-flow regime was maintained from August 2 through 10. Flows were reduced over the next seventy-two hours. Hydrologic and temperature conditions were allowed to stabilize over the following two days. The low flow regime was maintained from August 16 through 30.[3] Streamflow diversions did not occur during the experiment. Off-channel percolation ponds were supplied with imported water through pipeline transfers.

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[3] The original study design was to allow a fourteen-day period for each experimental flow regime. Because of a delayed start time and initial calibration adjustments, the high-flow period was limited to nine days for the temperature-streamflow analysis. The low-flow condition was maintained over a fifteen-day period.

Water Temperature Guidelines for Steelhead Habitat Suitability

According to the literature, incipient lethal and sublethal temperatures for steelhead/rainbow trout range from 25 to 28° C (77 to 82° F) and 20 to 25° C (68 to 77° F), respectively (Bell 1990; Moyle 1976; Piper et al 1982; Raleigh et al 1984). For this study suitable temperatures were defined as having mean daily temperatures below 20° C and hourly temperatures below 25° C. Similar tolerance criteria have been used by other researchers (U.S.EPA 1987; SYTAC 1997).

RESULTS

Water Temperatures above Reservoirs and Reservoir Effects on Water Temperature

Above Lexington, Guadalupe, and Almaden reservoirs, temperatures did not change substantially with distance upstream (Figure 5). Lexington and Guadalupe reservoirs had a cooling effect on temperatures downstream (Figure 6). At the end of August, however, Lexington Reservoir release temperatures increased abruptly and were warmer than inflow temperatures.

Vasona and Almaden reservoirs had a warming effect on stream temperatures (Figure 7). Almaden Reservoir outflow temperatures increased during the study period and were consistently warmer than reservoir inflow temperatures. Because the temperature monitoring device was missing from the Vasona Reservoir inflow station, temperature data were not available for comparison during the second half of the study (Figure 7).

Effects of Streamflow and other Factors on Water Temperature

Mean daily water temperatures generally increased with distance downstream. Exceptions were at two stations in Alamitos Creek and one in the Guadalupe River (Table 3). Mean daily reservoir release temperatures were significantly warmer during the low-flow period (Table 3, $p<0.05$). At several locations significant changes in mean daily water temperature occurred between the two test flow periods (Table 3, $p<0.05$).

In Guadalupe Creek, mean daily water temperatures were significantly higher during the low-flow period (Table 3, $p<0.05$). Downstream of the reservoir outflow station in Alamitos Creek, mean daily water temperatures were lower during the low-flow period. At three of these stations,

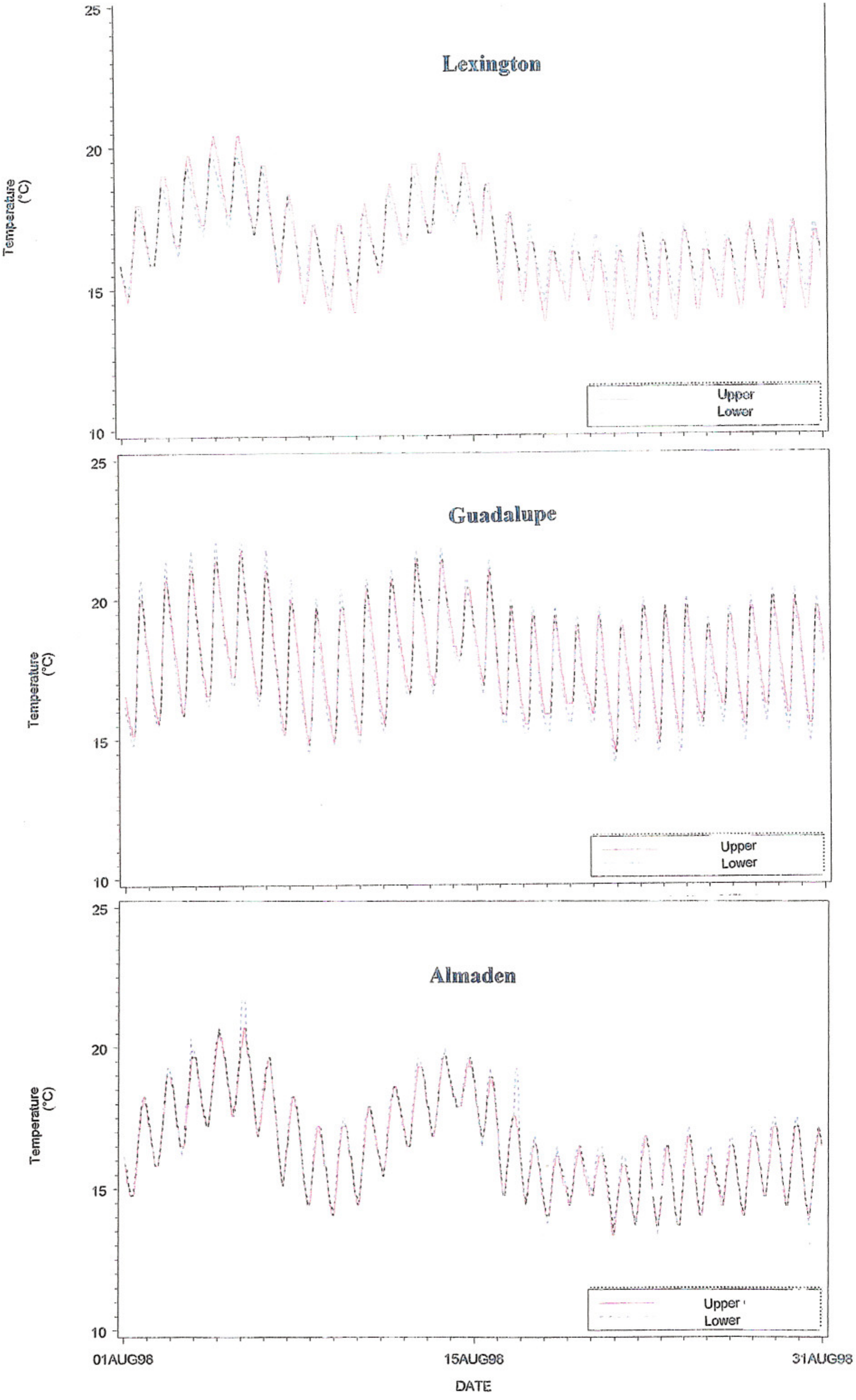
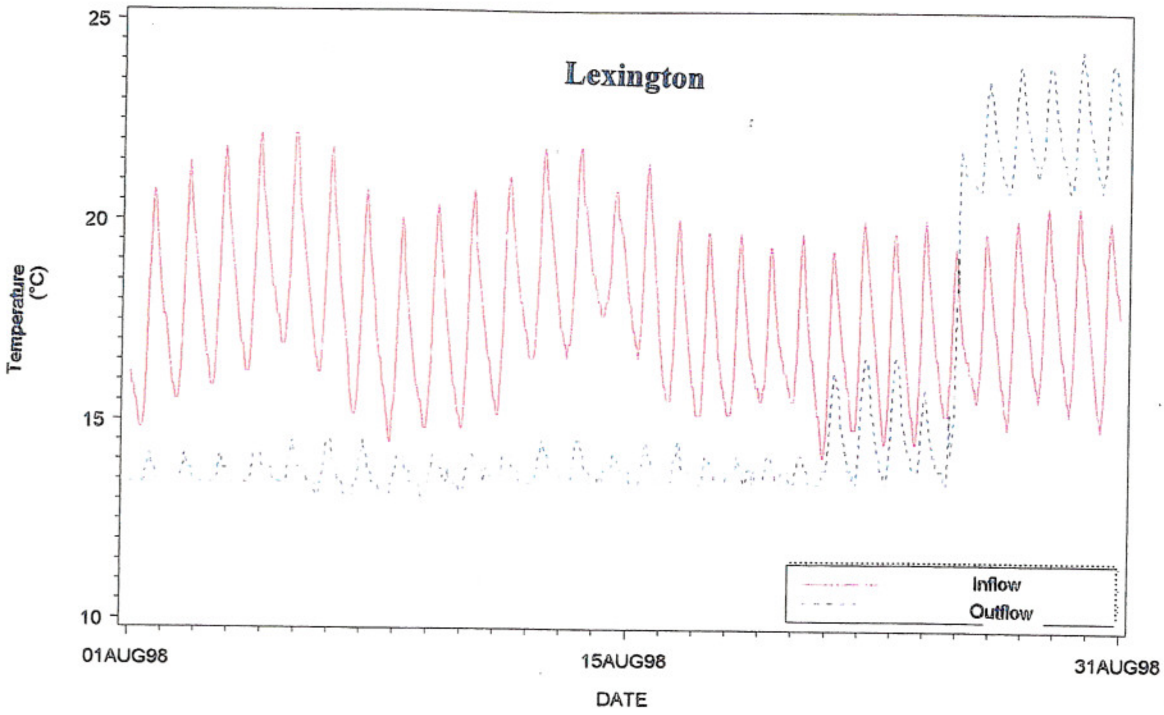


Figure 5. Hourly water temperatures upstream of Lexington. Guadalupe, and Almaden reservoirs.



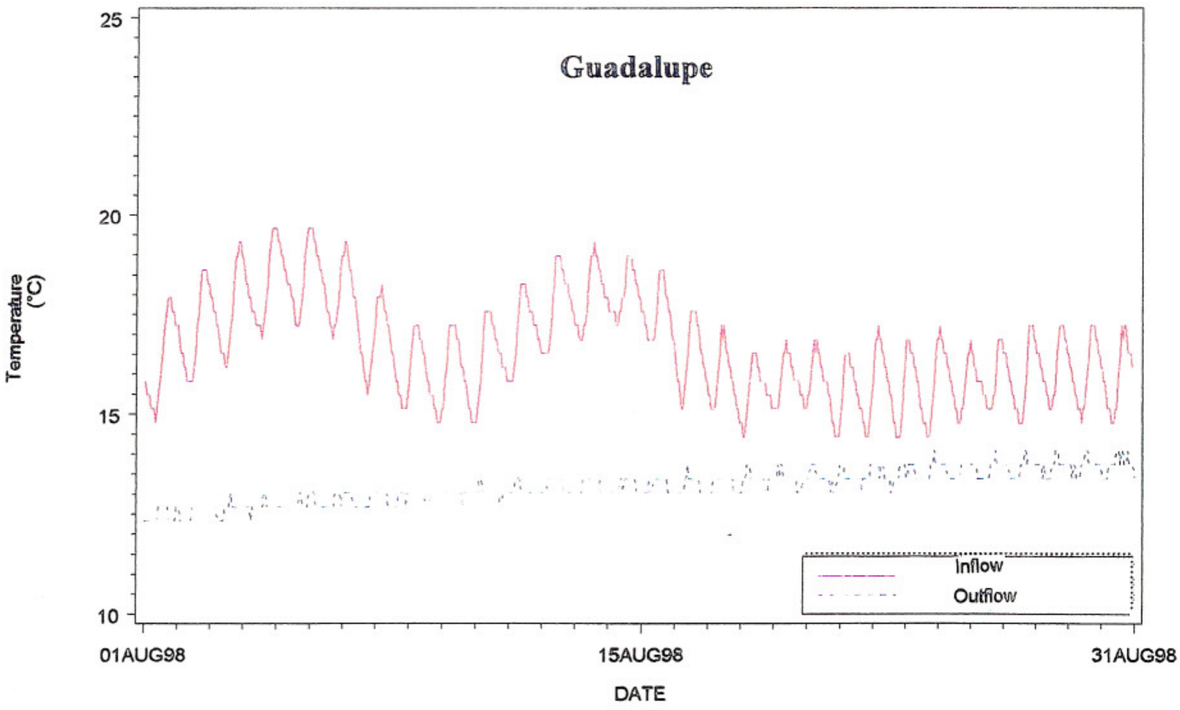
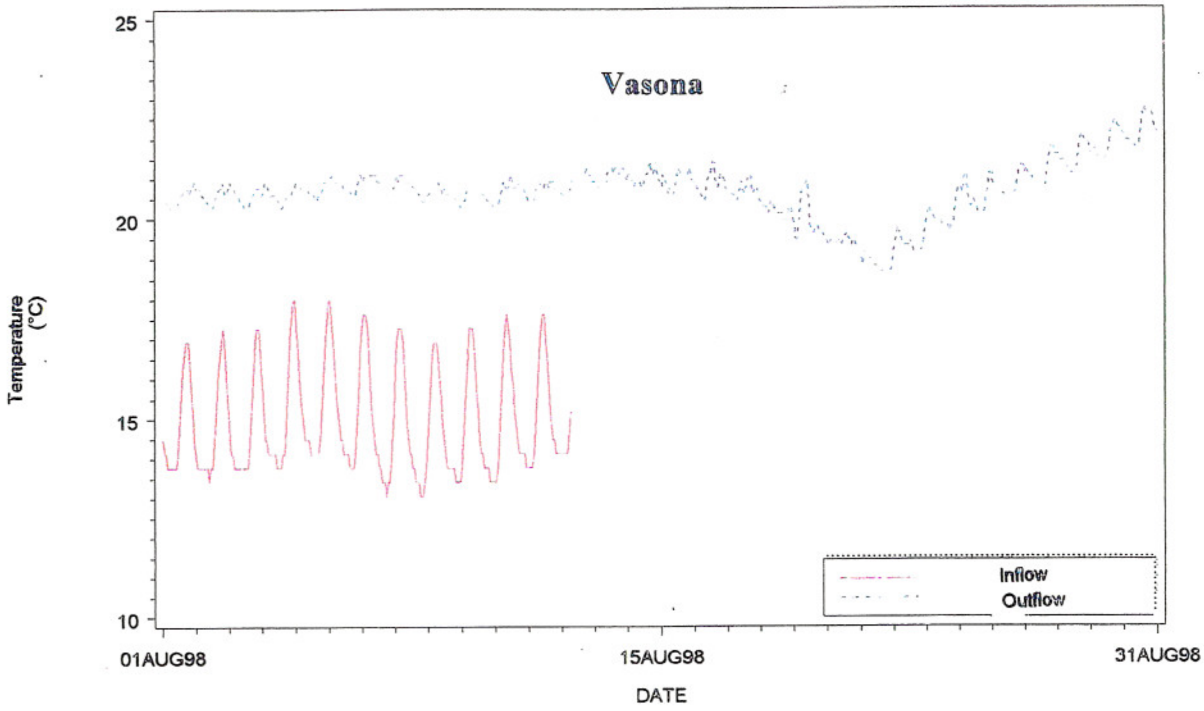


Figure 6. Hourly water temperatures at the inflow and outflow of Lexington and Guadalupe reservoirs.



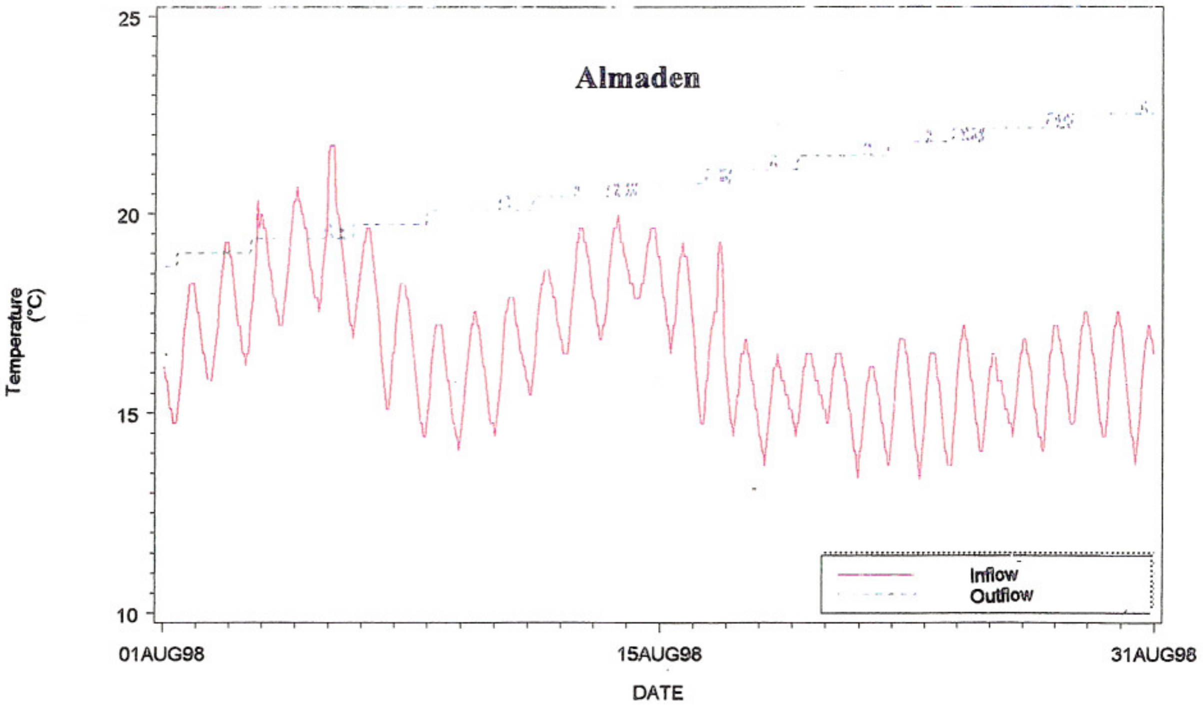


Figure 7. Hourly water temperatures at the inflow and outflow of Vasona and Almaden reservoirs.

Table 3. Mean daily water temperatures during the high- and low-flow test periods.

	Mean Daily Water Temperatures, °C							
	High-Flow Period			**Low-Flow Period**				
Station	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**(p)**	**Low-Flow Water Temperatures Higher or Lower**
Guadalupe Creek								
Guadalupe Reservoir Outflo	13.0	12.3	12.8	14.1	13.0	13.5	0.0001	Higher
Shannon Road	17.1	12.7	14.7	17.2	12.9	15.2	0.0001	Higher
Masson Dam	19.3	13.0	15.9	20.0	13.7	16.6	0.0001	Higher
Almaden Expressway	24.6	13.7	18.2	26.8	14.8	19.6	0.0001	Higher
Alamitos Creek								
Almaden Reservoir Outflow	20.4	19.0	19.6	22.9	20.8	21.8	0.0001	Higher
McKean Road	22.1	16.5	19.2	21.4	16.9	19.2	0.4806	Lower
Above Calero Creek	23.9	16.9	19.9	23.5	17.2	19.8	0.2052	Lower
Below Calero Creek	22.2	15.9	18.7	21.5	16.2	18.5	0.9172	Lower
Lake Almaden Inflow	25.7	16.5	20.7	23.9	16.5	19.9	0.0003	Lower
Calero Creek								
Calero Reservoir Outflow	15.5	13.1	13.6	15.2	13.1	13.8	0.0001	Higher
Fortini Road	19.0	12.3	15.2	18.7	12.0	15.0	0.7987	Higher
Above Alamitos Creek	19.0	15.2	17.3	18.0	15.5	16.9	0.0001	Lower
Guadalupe River								
Alamitos Drop Structure	26.7	24.2	25.4	26.4	23.9	24.5	0.0001	Lower
Branham Lane	28.2	21.5	24.2	26.4	20.4	23.0	0.0001	Lower
Stream Gauge 23B	28.9	24.2	26.8	27.1	23.5	25.2	0.0001	Lower

the temperature change was insignificant (Table 3, $p>0.05$). In Calero Creek, downstream of the reservoir outflow station, mean daily water temperatures were significantly lower during the low flow period at the station farthest downstream (Table 3, $p<0.05$). At the other location, temperature changes were not significant (Table 3, $p>0.05$).

Unusually high flows occurred in the Guadalupe River downstream of Los Gatos Creek. Because of this factor, streamflow effects on water temperature were not analyzed at stations adjacent to and downstream of the confluence. At the other three Guadalupe River stations, mean daily water temperatures were significantly lower during the low-flow period (Table 3, $p<0.05$).

During both flow regimes, patterns of diel variation in air temperature were strongly reflected in water temperature variations at each location (Figures 8-22). Air temperature was significantly lower during the low-flow period (Table 4). At most locations, air temperature had a greater effect on stream temperature than flow, reservoir release temperature, or time of day (Table 5).

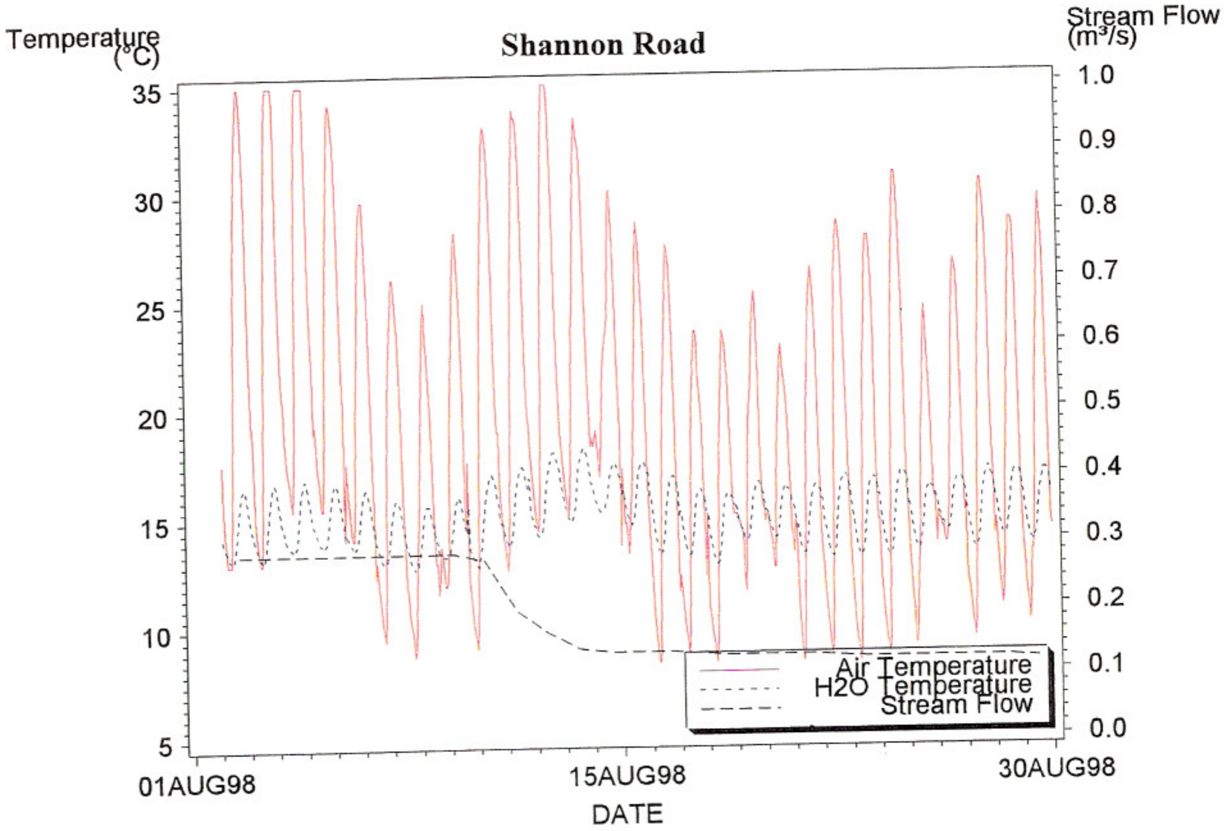


Figure 8. Hourly water temperature, air temperature, and streamflow, Guadalupe Creek at Shannon Road. (Air temperature from Shannon Road station; streamflow from Gauge 43).

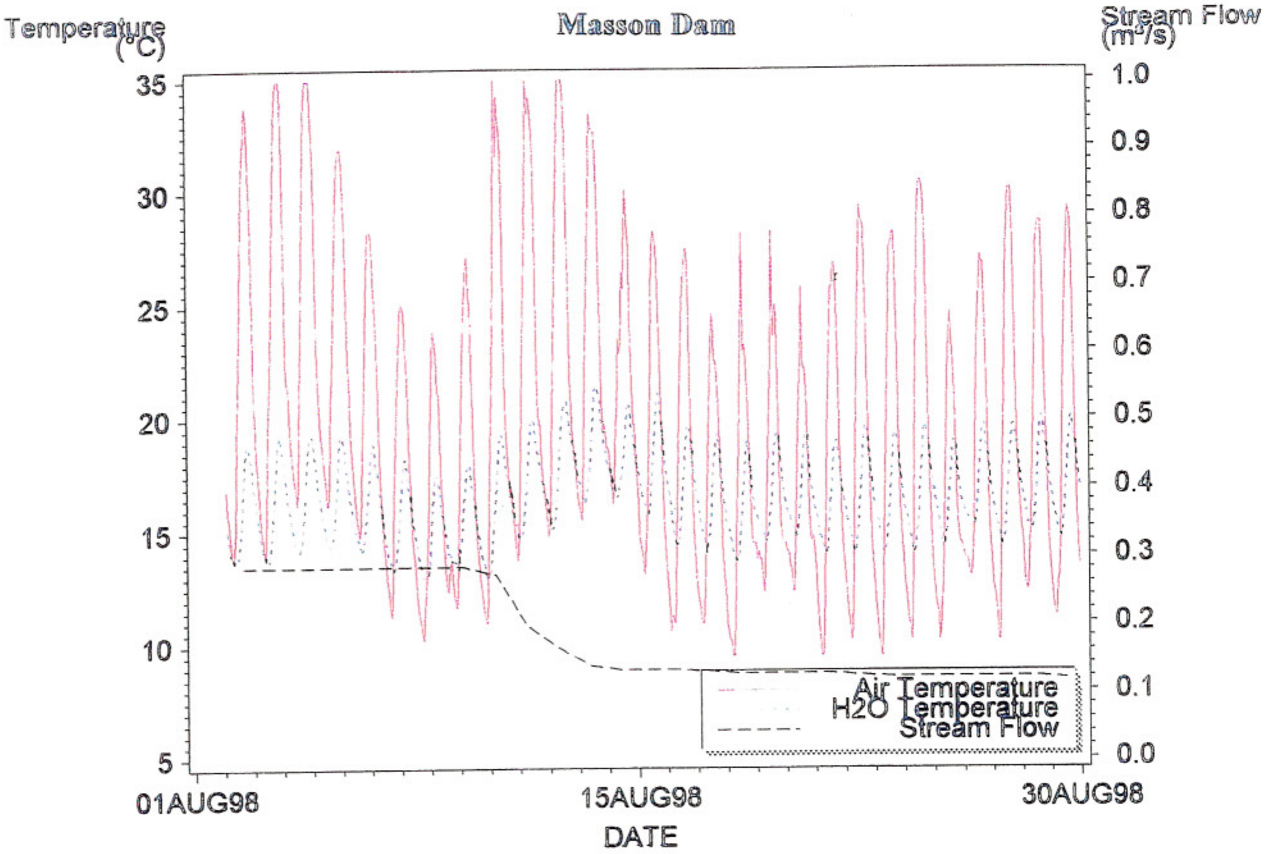


Figure 9. Hourly water temperature, air temperature, and streamflow, Guadalupe Creek at Masson Dam. (Air temperature from Masson Dam station; streamflow from Gauge 43).

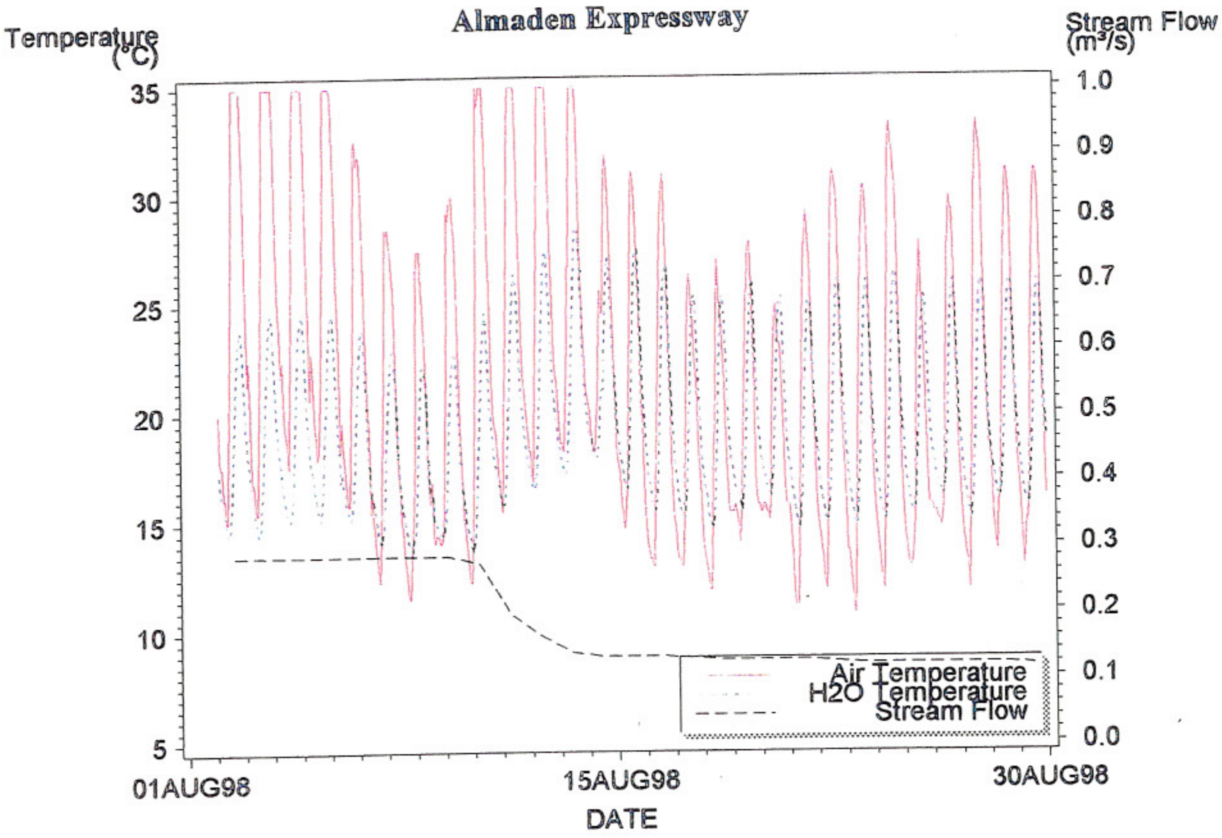


Figure 10. Hourly water temperature, air temperature, and streamflow, Guadalupe Creek at Almaden Expressway. (Air temperature from Almaden Expressway station; streamflow from Gauge 43).

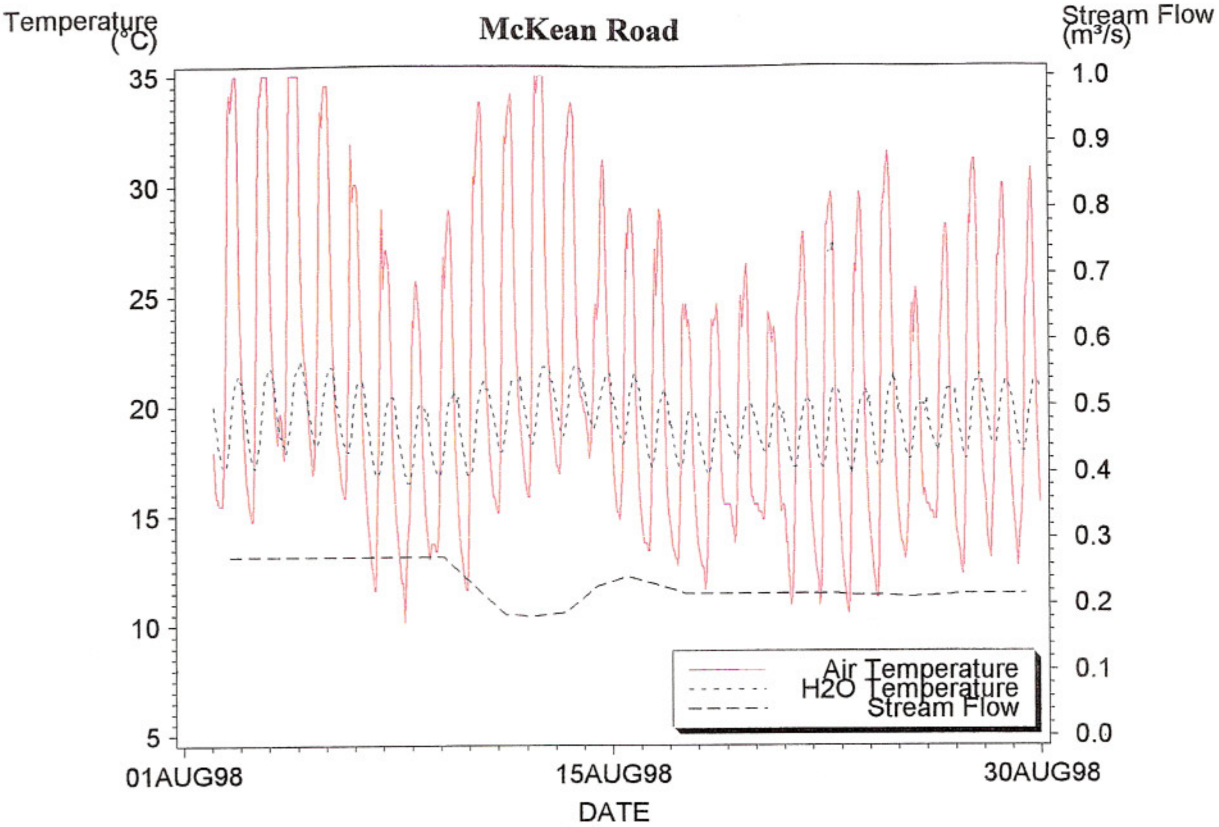


Figure 11. Hourly water temperature, air temperature, and streamflow, Alamitos Creek at McKean Road. (Air temperature from McKean Road station; streamflow from Gauge 16).

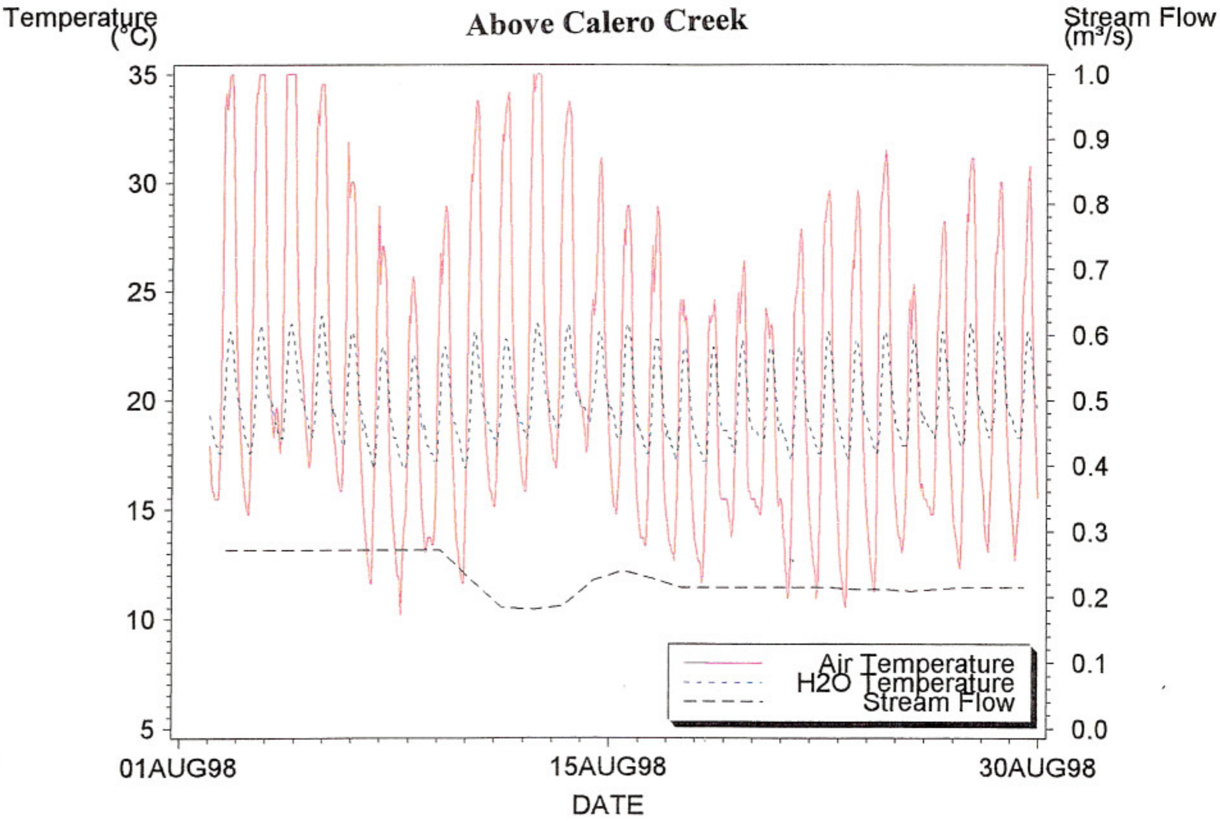


Figure 12. Hourly water temperature, air temperature, and streamflow, Alamitos Creek above the Calero Creek confluence. (Air temperature from Calero Creek above the Alamitos Creek confluence; streamflow from Gauge 16).

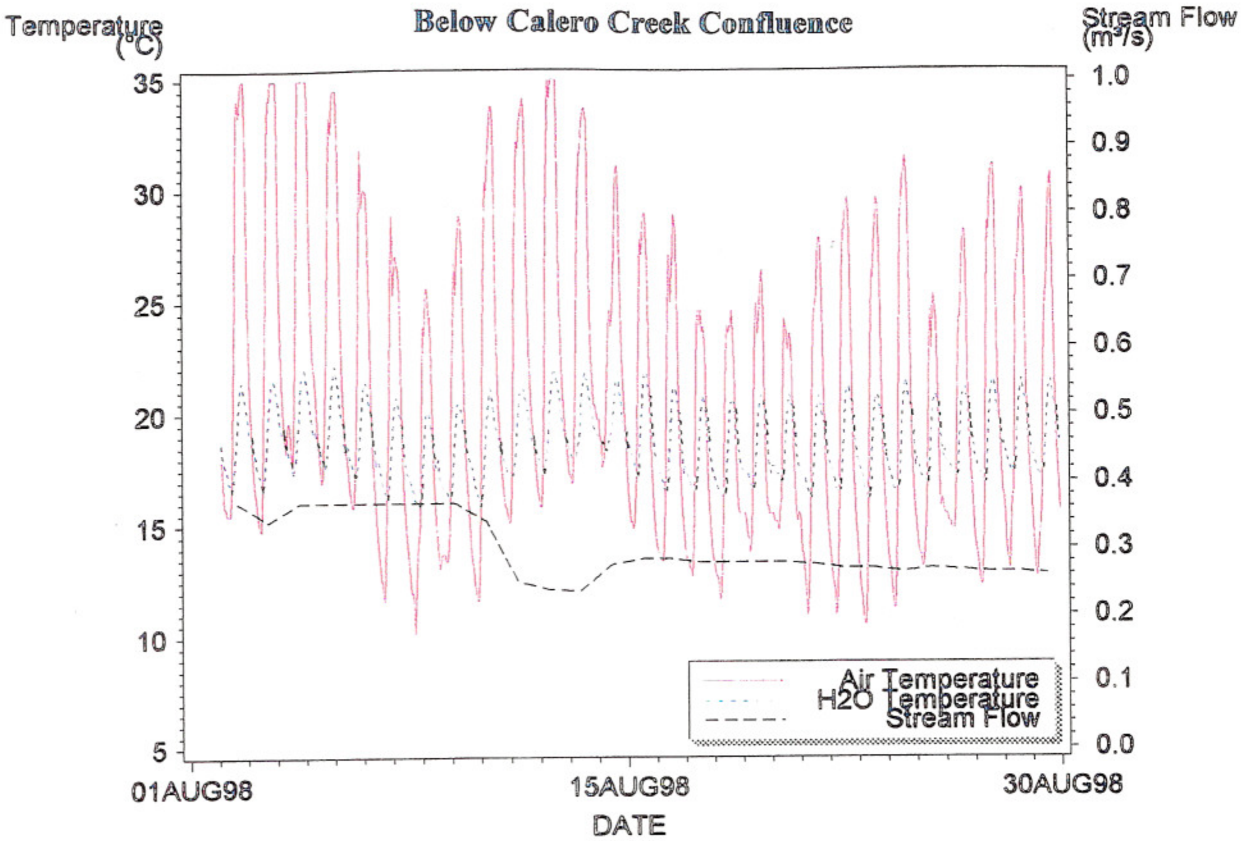


Figure 13. Hourly water temperature, air temperature, and streamflow, Alamitos Creek below the Calero Creek confluence. (Air temperature from Calero Creek above the Alamitos Creek confluence; streamflow from Gauge 16).

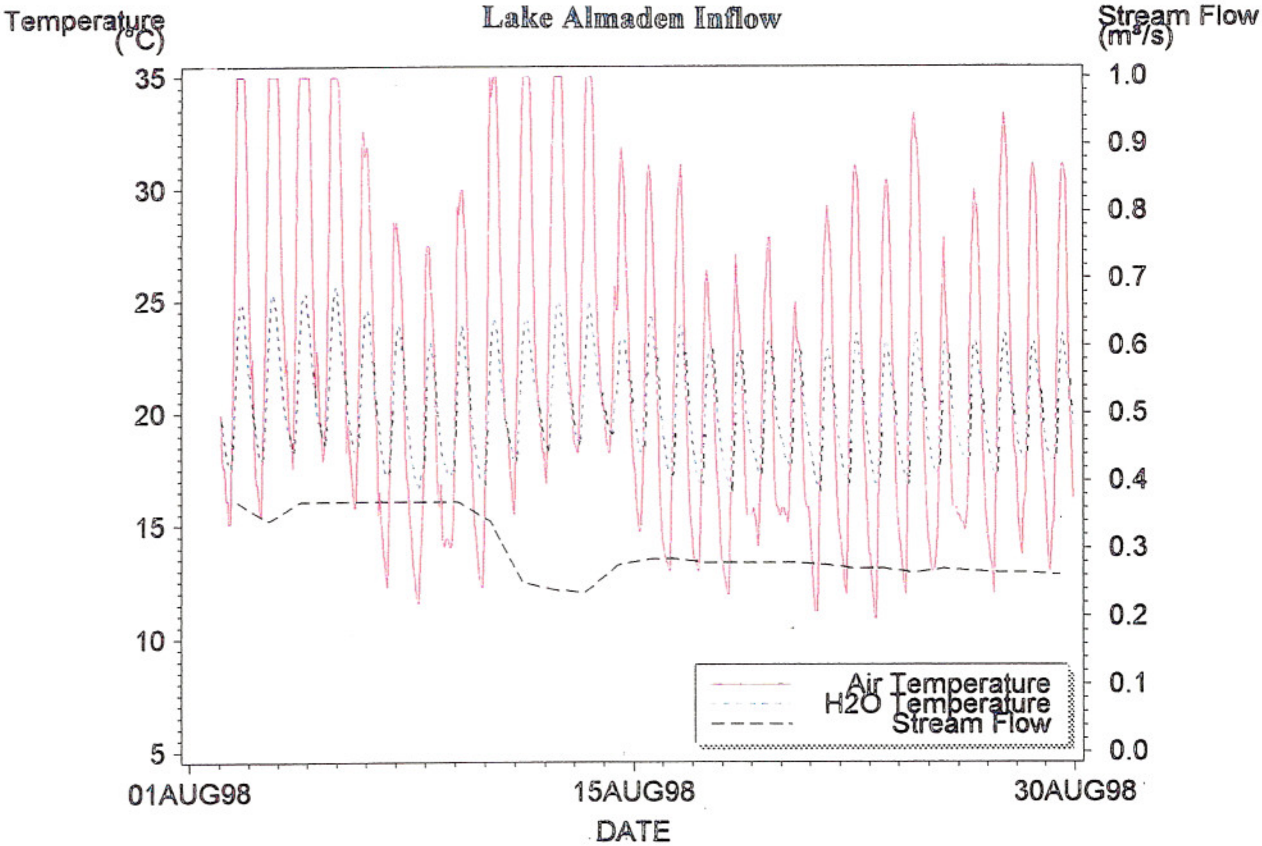


Figure 14. Hourly water temperature, air temperature, and streamflow, Alamitos Creek above Lake Almaden. (Air temperature from Guadalupe Creek at Almaden Expressway; streamflow from Gauge 70).

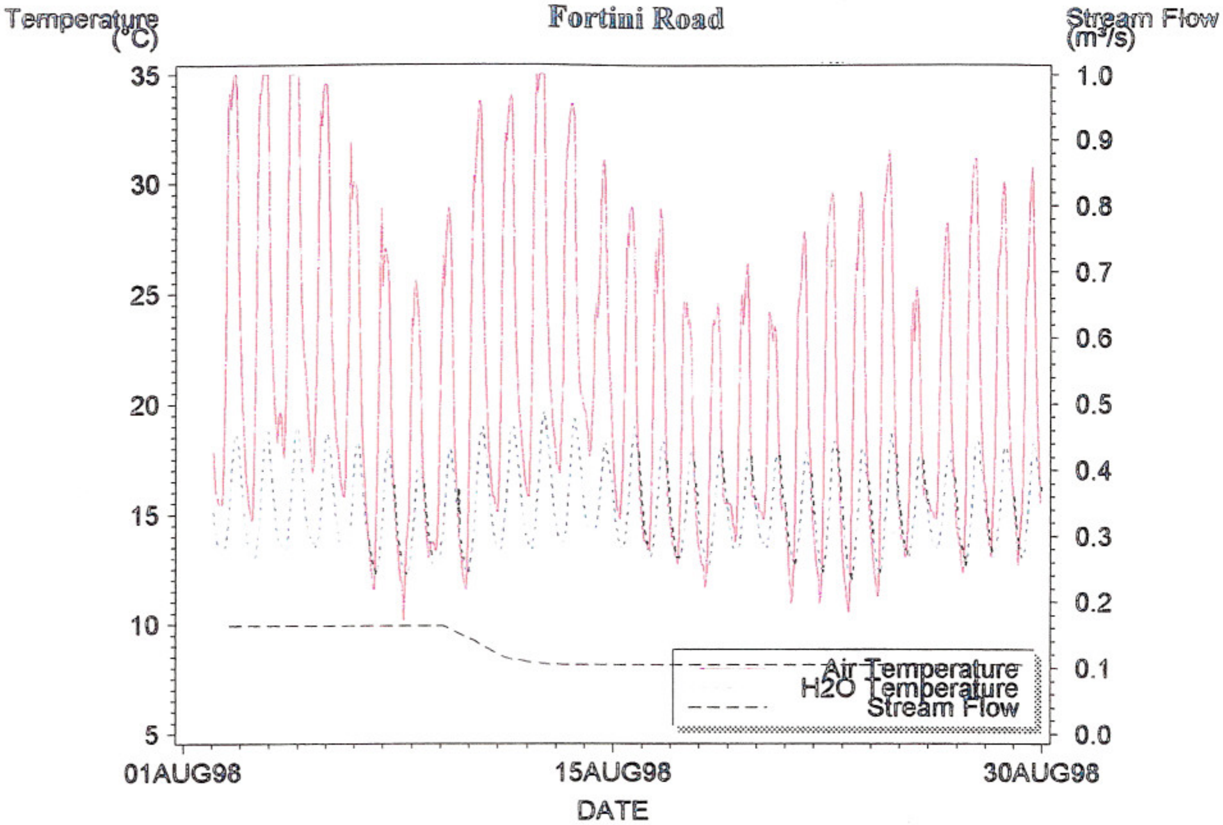


Figure 15. Hourly water temperature, air temperature, and streamflow, Calero Creek at Fortini Road. (Air temperature from above the Alamitos Creek confluence streamflow from Gauge 13).

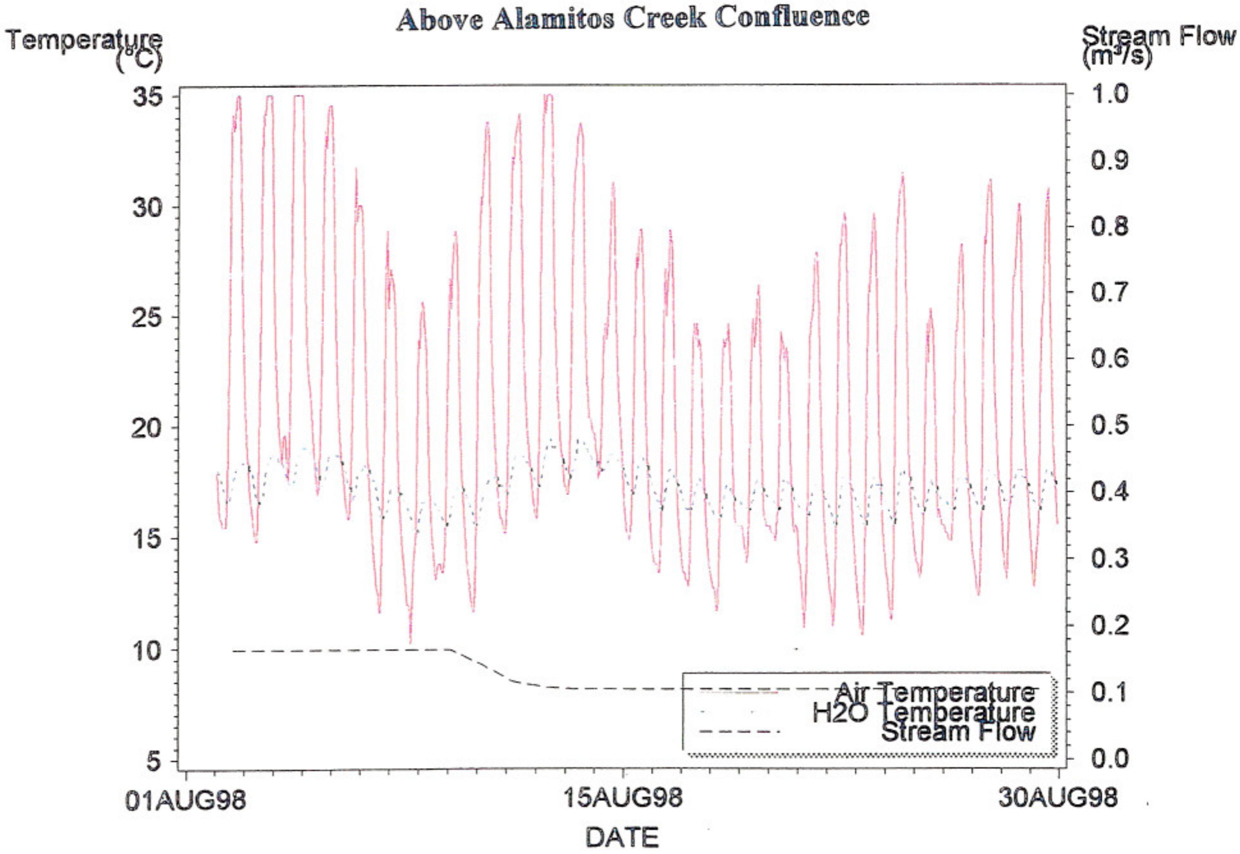


Figure 16. Hourly water temperature, air temperature, and streamflow, Calero Creek above the Alamitos Creek confluence. (Air temperature from Calero Creek above the Alamitos Creek confluence; streamflow from Gauge 13).

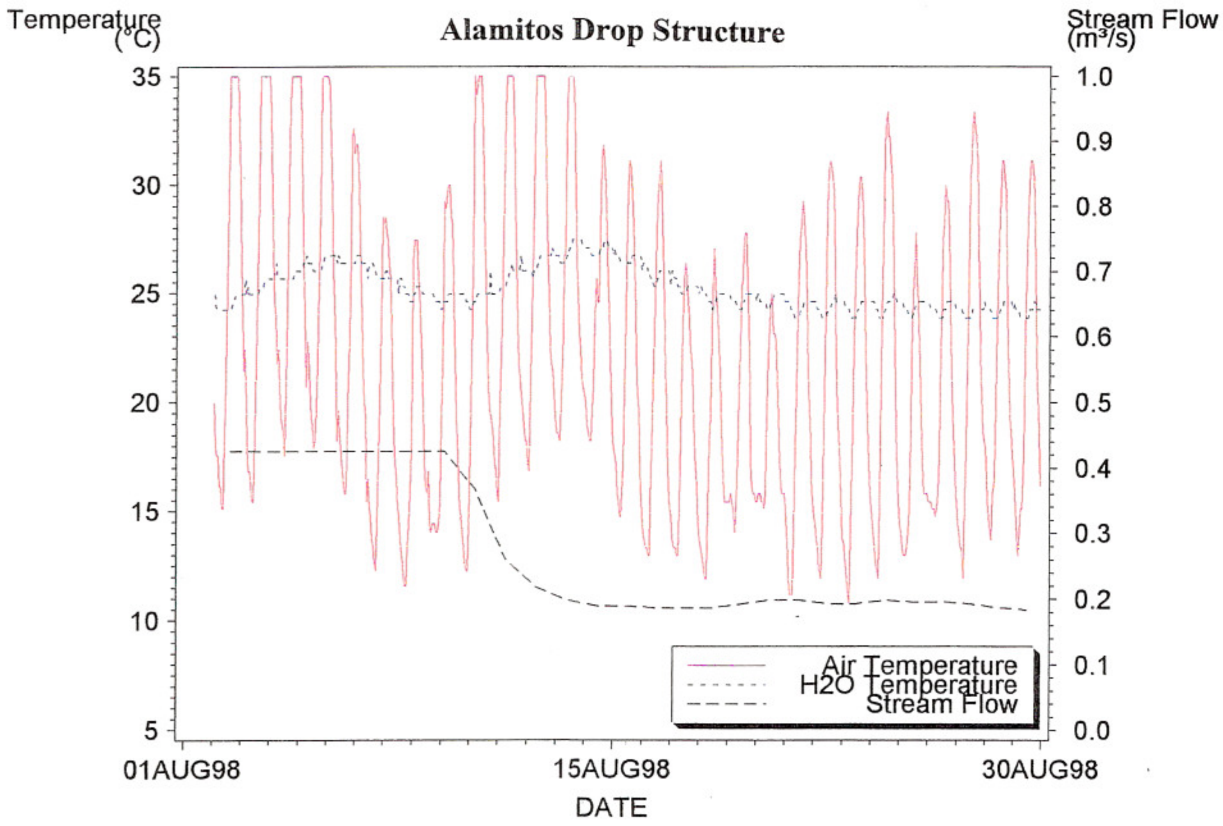


Figure 17. Hourly water temperature, air temperature, and streamflow, Guadalupe River at the Alamitos Drop Structure. (Air temperature from Guadalupe Creek at Almaden Expressway; streamflow from Gauge 20).

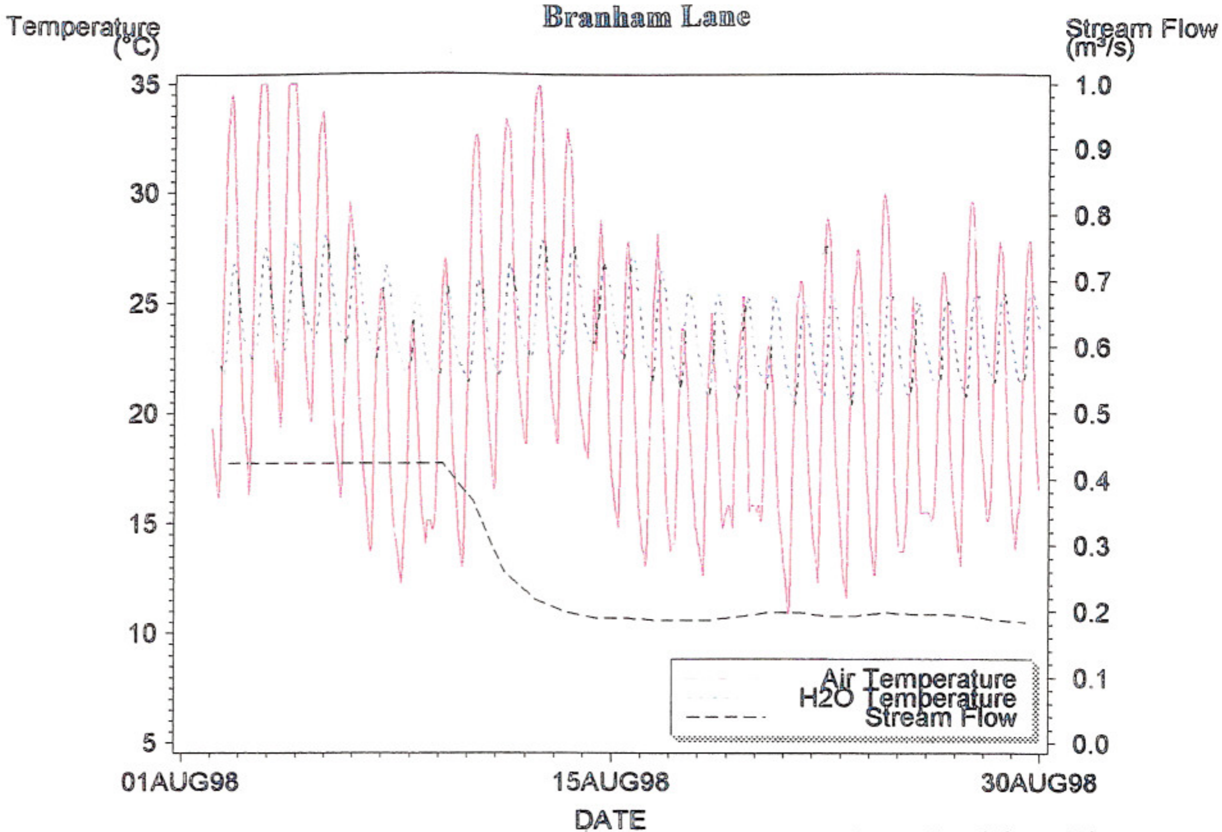


Figure 18. Hourly water temperature, air temperature, and streamflow, Guadalupe River at Branham Lane. (Air temperature from Guadalupe River at Gauge 23B; streamflow from Gauge 20).

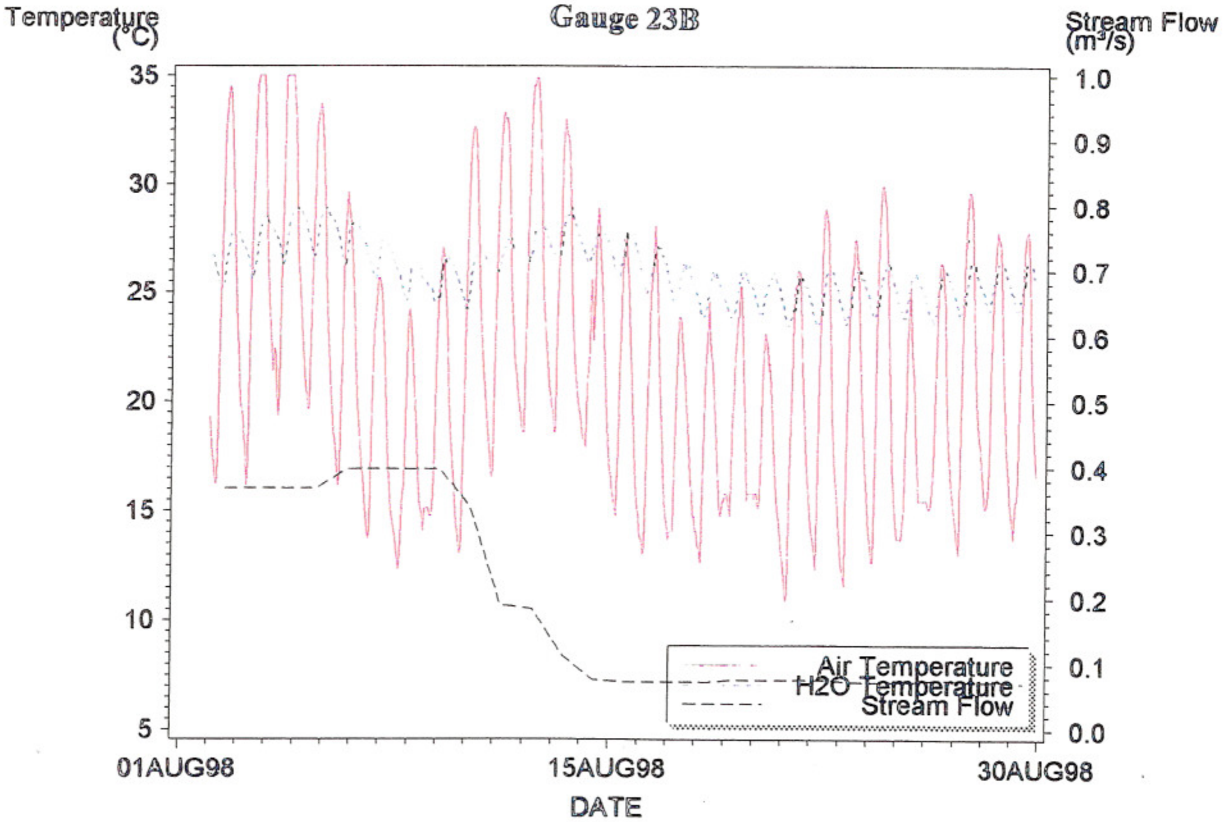


Figure 19. Hourly water temperature, air temperature, and streamflow, Guadalupe River at Gauge 23B. (Air temperature from Guadalupe River at Gauge 23B; streamflow from Gauge 23B).

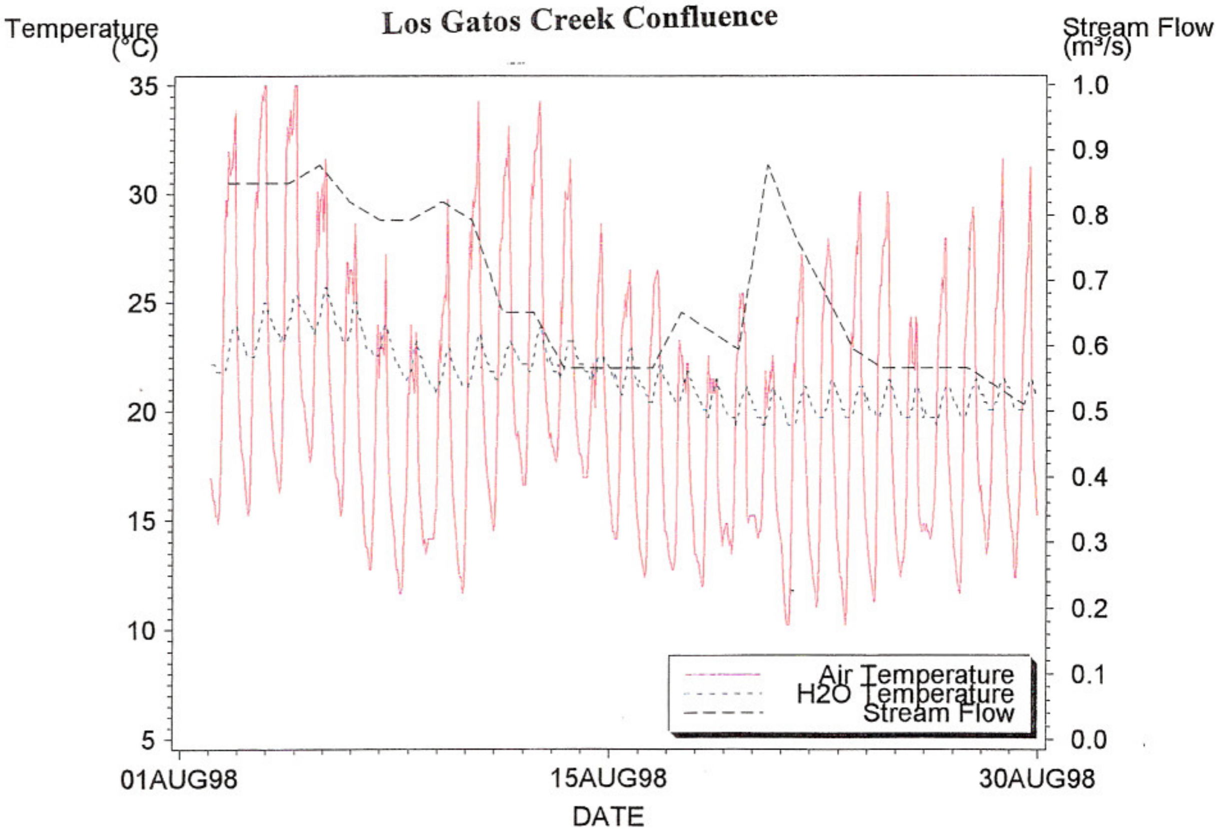


Figure 20. Hourly water temperature, air temperature, and streamflow, Guadalupe River at the Los Gatos Creek confluence. (Air temperature from Guadalupe River above Highway 880; streamflow from USGS Gauge).

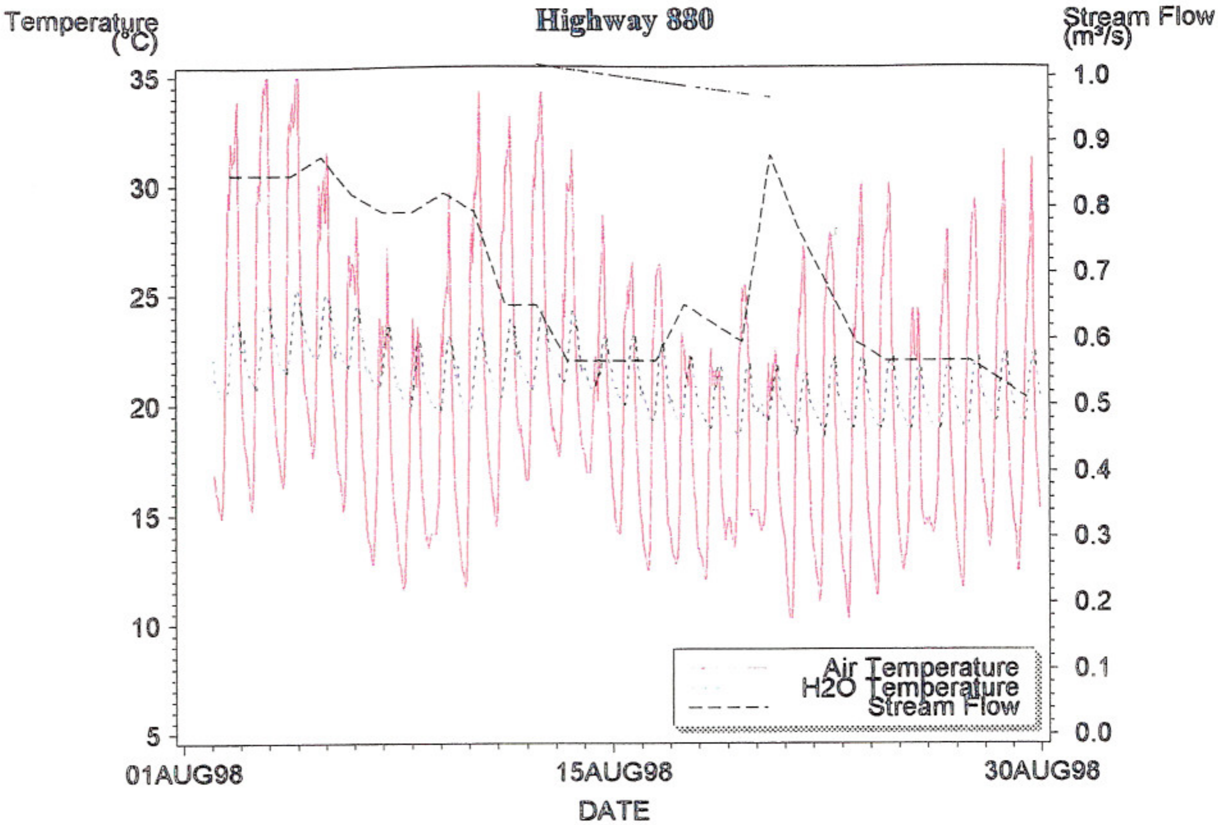


Figure 21. Hourly water temperature, air temperature, and streamflow, Guadalupe River above Highway 880. (Air temperature from Guadalupe River above Highway 880; streamflow from USGS Gauge).

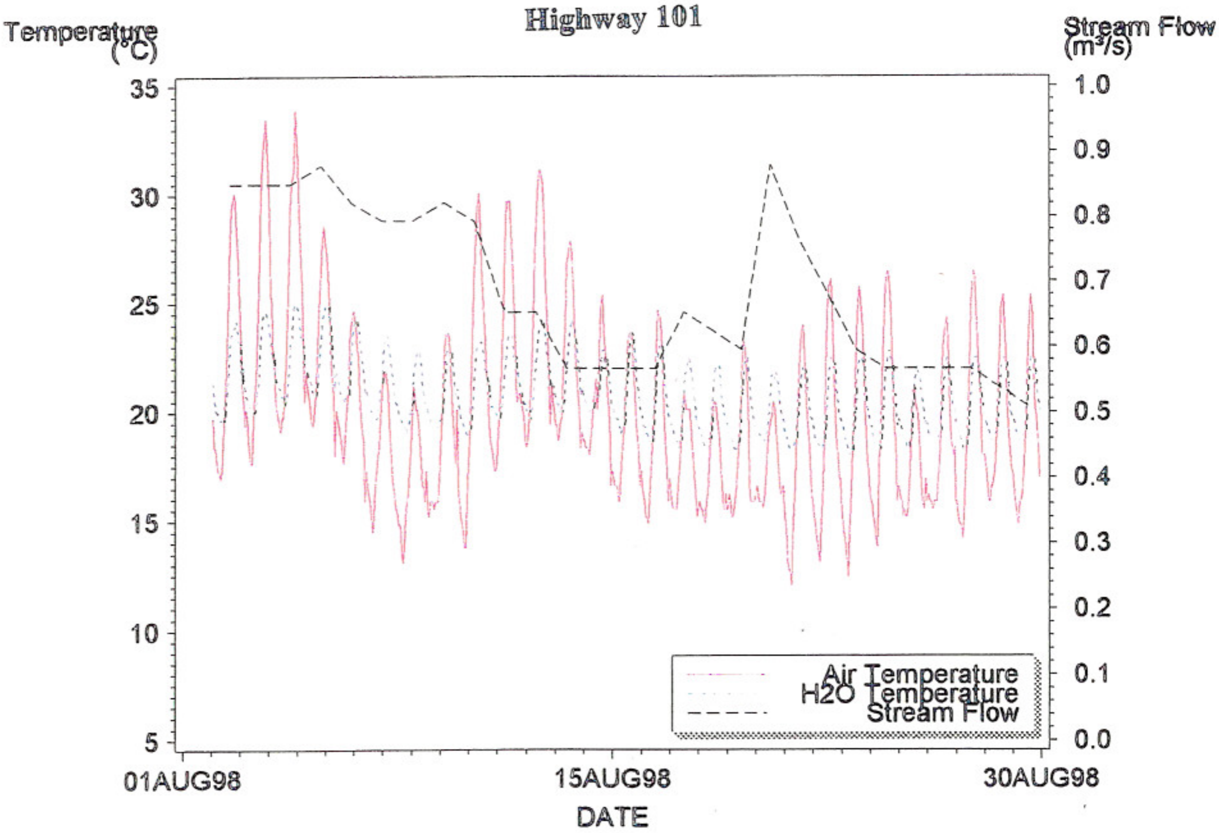


Figure 22. Hourly water temperature, air temperature, and streamflow, Guadalupe River at Highway 101 (Air temperature from Guadalupe River at Highway 101; streamflow from USGS Gauge).

Table 4. Mean daily air temperatures during the high- and low-flow test periods.

	Mean Daily Air Temperatures, °C							
	High-Flow Period			Low-Flow Period				
Station	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**(p)**	**Low-Flow Water Temperatures Higher or Lower**
Guadalupe Creek								
Shannon Road	37.8	8.8	21.3	30.8	8.4	18.0	0.0001	Lower
Masson Dam	40.7	10.2	21.1	30.4	9.5	18.3	0.0001	Lower
Almaden Expressway	40.6	11.6	23.8	33.4	10.9	20.2	0.0001	Lower
Calero Creek								
Above Alamitos Creek	38.9	10.2	22.4	31.5	10.6	19.4	0.0001	Lower
Guadalupe River								
Stream Gauge 23B	36.9	12.3	23.2	30.0	10.9	19.4	0.0001	Lower
Above Highway 880	37.0	11.7	21.4	31.6	10.3	18.5	0.0001	Lower
Highway 101	33.8	13.1	21.3	26.5	12.0	18.5	0.0001	Lower

Table 5. Multiple regression analysis of the relative significance of air temperature, streamflow, reservoir outflow temperature and flow, and time of day on water temperature.

	Multiple Linear Regression Analysis				
	(Partial R2)				
Station	**Air Temperature**	**Flow**	**Reservoir Outflow Temperature and Flow**	**Time of Day**	**R2**
Guadalupe Creek					
Shannon Road	0.4346	0.1799	0.0034	0.2437	0.8616
Masson Dam	0.4856	0.1710	0.0023	0.1670	0.8259
Almaden Expressway	0.6030	0.1306	0.0066	0.0639	0.8041
Alamitos Creek					
McKean Road	0.6177	0.0185	0.0169	0.1875	0.8406
Above Calero Creek	0.6961	0.0098	0.0502	0.0629	0.8190
Below Calero Creek	0.6409	0.0144	0.0131	0.1301	0.7985
Lake Almaden Inflow	0.7996	0.0047	0.0002	0.0710	0.8755
Calero Creek					
Fortini Road	0.3466	0.0596	0.0064	0.2927	0.7053
Above Alamitos Creek	0.3665	0.0359	0.0065	0.3583	0.7672
Guadalupe River					
Alamitos Drop Structure	0.0329	0.1969	0.3249	0.0559	0.6106
Branham Lane	0.5551	0.0066	0.0037	0.2007	0.7661
Stream Gauge 23B	0.3491	0.0561	0.0006	0.2628	0.6686
Los Gatos Creek Confluence	0.1113	0.0193	0.4228	0.1640	0.7174
Above Highway 880	0.3824	0.0370	0.0893	0.2721	0.7808
Highway 101	0.7407	0.0001	0.0261	0.1060	0.8729

Distribution and Quality of Suitable Water Temperatures for Rearing Steelhead

Upstream of Lexington, Vasona, Guadalupe, and Almaden reservoirs, water temperatures were suitable for rearing steelhead (Figure 23). Temperatures were unsuitable at the outflows of Lexington, Almaden, and Vasona reservoirs (Figure 23). Mean daily release temperatures exceeded 20° C at these three reservoirs (Table 6). Hourly temperatures were consistently below 25° C (Table 6).

Table 6. Frequency analysis of mean daily water temperatures above 20°C and hourly temperatures above 25°C.

	Mean Daily Temperature		Hourly Temperature	
Station	**n**	**n >20° C**	**n**	**n >25° C**
Lexington Reservoir				
Inflow	24	0	576	0
Outflow	24	5	576	0
Vasona Reservoir				
Inflow	9	0	216	0
Outflow	24	9	576	0
Guadalupe Reservoir				
Inflow	24	0	576	0
Outflow	24	0	576	0
Almaden Reservoir				
Inflow	24	0	576	0
Outflow	24	17	576	0

With one exception, the distribution of suitable water temperatures did not differ between the two flow regimes downstream of the reservoir outflow stations (Figure 23). In Guadalupe Creek at Almaden Expressway, temperatures were unsuitable only during the low-flow period (Tables 7 and 8). In Alamitos Creek at Lake Almaden Inflow, water temperatures were unsuitable during both flow regimes (Table 7). Conditions were more severe during the high-flow period, when hourly temperatures exceeded 25° C (Table 8). In Alamitos Creek at McKean Road, mean daily water temperatures exceeded 20° C only during one day of the high-flow period. Water temperatures were unsuitable in the Guadalupe River under both experimental flows (Tables 7 and 8). Hourly temperatures exceeded 25° C more frequently during the high-flow period (Table 8, $p<0.05$).

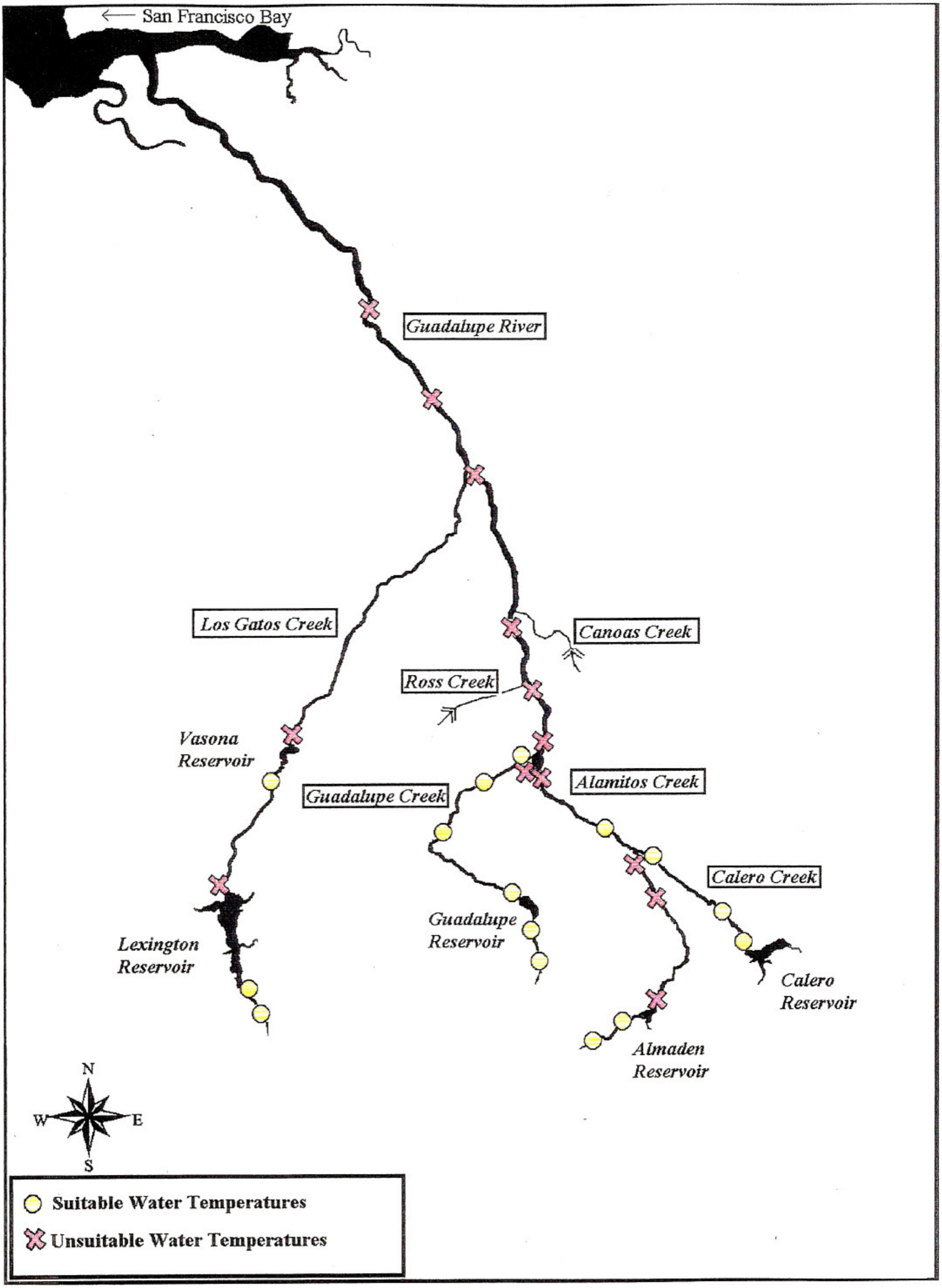


Figure 23. Geographic distribution of suitable and unsuitable water temperatures for rearing steelhead trout during August 1998.

Table 7. Frequency analysis of mean daily water temperatures above 20°C during the high- and low-flow test periods.

	Mean Daily Temperature, °C				
	High-Flow Period		Low-Flow Period		
Station	**n**	**n >20° C**	**n**	**n >20° C**	**(p)**
Guadalupe Creek					
Guadalupe Reservoir Outflow	9	0	15	0	n/a
Shannon Road	9	0	15	0	n/a
Masson Dam	9	0	15	0	n/a
Almaden Expressway	9	0	15	2	0.263
Alamitos Creek					
Almaden Reservoir Outflow	9	2	15	15	0.001
McKean Road	9	1	15	0	0.197
Above Calero Creek	9	4	15	5	0.720
Below Calero Creek	9	0	15	0	n/a
Lake Almaden Inflow	9	7	15	6	0.078
Calero Creek					
Calero Reservoir Outflow	9	0	15	0	n/a
Fortini Road	9	0	15	0	n/a
Above Alamitos Creek	9	0	15	0	n/a
Guadalupe River					
Alamitos Drop Structure	9	9	15	15	n/a
Branham Lane	9	9	15	15	n/a
Stream Gauge 23B	9	9	15	15	n/a

Table 8. Frequency analysis of hourly water temperatures above 25°C during the high- and low-flow test periods.

	Hourly Water Temperature, °C				
	High-Flow Period		Low-Flow Period		
Station	**n**	**n >25° C**	**n**	**n >25° C**	**(p)**
Guadalupe Creek					
Guadalupe Reservoir Outflow	216	0	360	0	n/a
Shannon Road	216	0	360	0	n/a
Masson Dam	216	0	360	0	n/a
Almaden Expressway	216	0	360	41	0.001
Alamitos Creek					
Almaden Reservoir Outflow	216	0	360	0	n/a
McKean Road	216	0	360	0	n/a
Above Calero Creek	216	0	360	0	n/a
Below Calero Creek	216	0	360	0	n/a
Lake Almaden Inflow	216	8	360	0	0.001
Calero Creek					
Calero Reservoir Outflow	216	0	360	0	n/a
Fortini Road	216	0	360	0	n/a
Above Alamitos Creek	216	0	360	0	n/a
Guadalupe River					
Alamitos Drop Structure	216	121	360	15	0.001
Branham Lane	216	78	360	15	0.001
Stream Gauge 23B	216	198	360	15	0.001

In the three lower Guadalupe River stations, where temperatures were not analyzed between the two experimental flows, water temperatures were unsuitable for rearing steelhead (Figure 23). At the two lower stations, hourly temperatures did not exceed 25° C (Table 9).

Table 9. Frequency analysis of mean daily water temperatures above 20°C and hourly tempeatures above 25°C.

	Mean Daily Temperature		Hourly Temperature	
Guadalupe River Station	**n**	**n >20° C**	**n**	**n >25° C**
Los Gatos Creek	24	24	576	9
Highway 880	24	22	576	3
Highway 101	24	19	576	0

DISCUSSION

Upstream of Lexington, Guadalupe, and Almaden reservoirs, habitats were potentially suitable for rearing steelhead, based on water temperature. Steelhead access to these areas is currently blocked by dams and other barriers. Resident rainbow trout populations occur in these areas and may be included in future recovery plans for steelhead.

In general, shallow reservoirs cause a warming effect while deep reservoirs tend to cool temperatures downstream. However, this pattern varies in response to several factors, including reservoir depth and contour, inflow rate and temperature, outflow rate and location, local air temperature, and surrounding topography.

Within the parameters of this study, results were consistent with the general pattern described above. The relatively shallow reservoirs, Vasona and Almaden, had a warming effect on stream temperatures. Warm-water releases from these reservoirs may significantly influence temperatures downstream. During most of the study period, Lexington and Guadalupe, the deeper reservoirs, had a cooling effect.

The sudden increase in temperatures released from Lexington Reservoir coincided with a change in reservoir operations. During dam safety inspections and repairs, water was pumped from the surface rather than being released from the outlet pipe at the base of the reservoir. Alternative methods are being explored for future dam safety operations (Reiller, pers. comm.).

Downstream of the reservoirs, differences between the high- and low-flow regimes, although statistically significant, represented a relatively narrow range of experimental flows. This factor may have adversely affected the ability to detect and quantify the effects of streamflow on temperatures downstream.

In future studies consideration should be given to comparing experimental flows that, if possible, represent a larger difference in flows than those tested during the August 1998 study. Further investigations of reservoir profiles, and reservoir inflow and outflow rates, would greatly increase our understanding of alternative flow regimes that would provide suitable temperatures downstream during a given year. These data would be especially useful during low water-years, when streamflow experiments may not be feasible.

In the Guadalupe River as well as the lower reaches of Guadalupe and Alamitos Creeks, substantial reservoir releases may be required to overcome the effects of air temperature and provide suitable water temperatures for rearing steelhead. Reservoir releases required to achieve this objective during the summer months may likely exhaust the volume of cold water available in the reservoirs upstream, especially during relatively low water-years. Other factors may include riparian shading, reservoir release temperatures, and effluent seepage.

In Guadalupe Creek at Almaden Expressway, water temperatures were unsuitable for rearing steelhead during the low-flow regime. This location is characterized by sparse vegetation, shallow water, and low gradient. These combined factors may have contributed to the effects of air temperature. Warm-water seepage from adjacent percolation ponds is also known to occur at this location (Aguilera, pers. comm.). Relatively greater impacts from pond seepage may have been facilitated by lower stream flows. At several locations in the upper tributaries, water temperatures were significantly higher during the low-flow regime despite cooler air temperatures during this period. Although reservoir release temperatures were higher during the low-flow test period, this factor was not as significant as air temperature for most locations.

Cool effluent seepage may also contribute to stream temperatures, especially in the lower reaches. In Santa Clara County, the water table was at a relatively high level compared to previous years (Akin, pers. comm.). This factor may have contributed to cooler stream temperatures at some locations, especially during the low-flow period. Further study on groundwater influence is needed to fully evaluate streamflow-temperature relationships. In addition a significant number of outfall releases affect the surface waters in Santa Clara County (Shay, pers. comm.). This variable also needs further study.

Several locations in the upper tributaries were potentially suitable, based on temperature, during both flow regimes. Barriers presently preclude anadromous steelhead from accessing a majority of these areas. However, following the installation of a fish passage facility at the Alamitos Drop Structure in October 1999, a majority of these reaches may be open to steelhead migration. Additional thermal refugia may also occur at locations further downstream, between the stations monitored during this study. Thermal refugia may result from influences such as cool outfall releases and effluent seepage.

The temperature tolerances defined for this analysis were primarily founded on results of laboratory investigations using steelhead and rainbow trout from the northern part of their geographic distribution, such as Oregon and Washington. Santa Clara County is located near the southern range for steelhead, where higher temperatures may be tolerated. However, no definitive data are available. In the absence of more data on temperature tolerances of southern steelhead and rainbow trout populations, these thermal criteria should be used as general guidelines rather than absolute thresholds.

Steelhead trout have very plastic life histories. The majority may remain in the freshwater system year-round or emigrate to marine habitats before temperatures reach sublethal limits. While the highest water temperatures may typically occur in August, no data are available to substantiate what percentage of the steelhead population inhabits these areas during this period. Temperatures should also be evaluated during other months when tolerance limits may be exceeded for different life stages.

Fisheries management strategies regarding streamflow should not be based solely on stream temperature analyses. Further implications of this study will be addressed following the analysis of streamflow effects on physical characteristics of steelhead rearing habitat in Guadalupe Creek.

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